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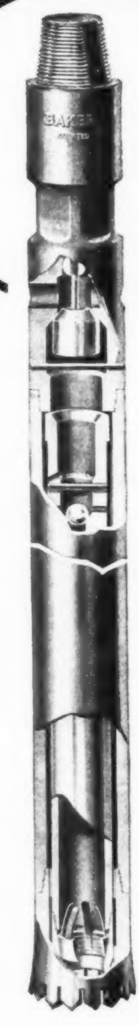
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Volume 17 Number 4

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

APRIL 1933

Colorado Symposium

PREFACE

Many efforts have been made to discover oil and gas in the Plains Province of eastern Colorado and the neighboring states, but without material success until oil was found in the Greasewood area in northeastern Colorado. That development, although not yet entirely satisfactory, has stimulated activity and caused additional drilling which has added new facts about the geology of the area.

Oil in commercial quantities has previously been developed in the Fort Collins and Wellington fields in Laramie County and in the Florence and Cañon City fields in Fremont County. Oil or gas in small quantities has been found also at Berthoud in Laramie County, near Trinidad in Las Animas County, and near Wray in Yuma County. The Fort Collins and Wellington fields are on large anticlines of the regular Rocky Mountain type, and the Berthoud field is on a smaller structure. The Florence and Cañon City fields produce oil from fractures in Cretaceous shale and are not on closed anticlines.

All the occurrences listed are limited to beds of Cretaceous age. All of the older fields are close to the foothills of the Rocky Mountains. If oil or gas in commercial quantities is to be found in northeastern Colorado, it is quite probable that its occurrence will be unlike that in the typical Rocky Mountain fields, because the beds are relatively low-dipping on the plains.

Enough drilling has been done in the vicinity of the Greasewood pool to demonstrate that the subsurface structure is radically different from the surface. Immediately the question arises whether the present wells were properly located to test adequately the oil possibilities of the area.

The present symposium does not attempt to describe the geology of any locality. It does attempt to outline the regional geology and

the regional changes in formations in such a way that the newcomer to eastern Colorado can better understand the fundamental geology of the Cretaceous formations and also of the older formations so far as a study of the outcrops makes it possible.

There are oil possibilities in eastern Colorado both in Cretaceous beds and in Pennsylvanian and pre-Pennsylvanian beds. A large area in northeastern Colorado is considered a Cretaceous province. Because these beds are here thick, the depth to the older horizons is at present excessive. Another large area in southeastern Colorado has such a thin covering of Cretaceous that the only possibilities are in Pennsylvanian and pre-Pennsylvanian beds. In the intervening area oil and gas may be found in either or both groups. The northeastern Colorado or Cretaceous province, the one of immediate interest, is bounded on the west by the foothills, on the south by Arkansas River or a line north of that river, and extends east into Kansas and north to the Black Hills of South Dakota.

The southeastern province in which Pennsylvanian and pre-Pennsylvanian beds may be of interest is more difficult to outline. Two papers in this symposium are devoted to facts gained from very careful study of these older formations at the outcrop in the mountainous part of central Colorado. Obviously the relationships revealed by this study are of first importance in planning any exploration campaign in preparation for drilling pre-Pennsylvanian formations. The Marland Oil Company's Pipe Springs well, in Bent County, established the presence of the pre-Pennsylvanian formations in the plains province which have produced oil farther east in Kansas.

C. E. Dobbin, of Denver, who has recently been appointed editor in the Rocky Mountain region, deserves special thanks for the unusual effort he has put forth assisting in the preparation of this symposium, and to all others who have contributed I wish to express my warm appreciation.

R. Clare Coffin

Denver, Colorado
February, 1933

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 4 (APRIL, 1933), PP. 353-374, 5 FIGS.

MEANING OF UNCONFORMITIES IN STRATIGRAPHY OF CENTRAL COLORADO[1]

T. S. LOVERING[2] and J. HARLAN JOHNSON[3]
Golden, Colorado

ABSTRACT

The paper is based on information obtained by the writers and other members of the United States Geological Survey between 1927 and 1932. The stratigraphy of central Colorado is briefly described. Unconformities occur at the base of the Cambrian, within the Ordovician, and beneath the Devonian, Mississippian, and Pennsylvanian deposits. The thickening and thinning of beds beneath the unconformities and overlaps are described and illustrated by sections. Apparently the Harding and Fremont formations of the Ordovician were originally much more widely distributed than at present. Long intervals of erosion preceded the deposition of the Devonian and the Pennsylvanian deposits, during which large amounts of earlier sediments were removed.

The erosion indicated by the widespread unconformities is comparatively small throughout much of the region, but in a narrow northerly trending zone on the western side of the Gore Mountains the erosion during each interdepositional period was so severe that nearly all the material just deposited was removed. The irregular, interrupted succession of overlap in this zone gives field evidence for the persistence of the Front Range Highland.

INTRODUCTION

During the summers of 1927, 1928, 1929, 1930, and 1931, several mining districts in central Colorado were studied in detail by members of the United States Geological Survey, and much new stratigraphic information has gradually accumulated. The detailed work in mineralized areas by Behre, Butler, Loughlin, Lovering, Singewald, and Vanderwilt showed the need for subdividing the geologic units formerly used in this region. At field conferences with David White, J. B. Reeside, Jr., and Edwin Kirk, the stratigraphy was revised and the subdivisions used in this paper were in large part agreed upon. The detailed work in the various mining districts has been correlated and extended partly by the work of the men previously named and partly by the regional stratigraphic studies of J. Harlan Johnson during the summers of 1930 and 1931.

Detailed studies have been made in the Leadville area by G. F. Loughlin and C. H. Behre, Jr.; in the Alma district by B. S. Butler and Q. D. Singewald; in the Breckenridge and Montezuma districts by

[1] Published by permission of the director, United States Geological Survey and the Colorado Geological Survey Board.

[2] United States Geological Survey.

[3] Associate professor of geology, Colorado School of Mines.

T. S. Lovering; in the Snowmass or Marble district by J. W. Vanderwilt. Reconnaissance studies have been carried on in the southern Mosquito Range by C. H. Behre, Jr., B. S. Butler, E. N. Goddard, and Q. D. Singewald; in the Taylor Park region by C. H. Behre, Jr., B. S. Butler, W. S. Burbank, and E. N. Goddard; in the Front Range, Gore Range, Park Range, and northern Elk Mountains by T. S. Lovering. The regional stratigraphic studies of J. Harlan Johnson, involving the measurement of many sections of both the upper and lower Paleozoic formations, extended from the southern Mosquito Range north through the Leadville and Alma districts to Minturn and southwest along the northern and western sides of the Sawatch Range from Minturn to the northern edge of Taylor Park. Although several papers have appeared that give some of the new information on the Paleozoic stratigraphy (see Bibliography), the field data accumulated by the writers and the other members of the United States Geological Survey have not been correlated in such a way as to make the regional significance of the unconformities and changes in lithology clear.

Unconformities are of great importance to the stratigrapher. They represent intervals of time during which not only had sedimentation ceased, but an unknown amount of material had been removed. Where unconformities are accentuated in a zone of unsystematic overlaps, they suggest the presence of a near-by positive element and are helpful in developing paleogeography. In this paper, the writers attempt to summarize the Paleozoic stratigraphy of central Colorado and to show its bearing on the geologic history of the region, especially in regard to the Front Range Highland as it existed during the Paleozoic and early Mesozoic eras.

General Geology

The Front Range is an elongate, oval uplift ranging from 20 to 50 miles in width, extending north from Cañon City, Colorado, to the vicinity of Laramie, Wyoming. The Park Range in Wyoming is separated from the Front Range on the east by a broad basin. As the Park Range is followed south, however, the basins which separate it from the Front Range narrow, and in the region south of Colorado River the southern continuation of the Park Range, known as the Gore Range, is separated from the Front Range system by the valley of Blue River, which is only a few miles wide. Northeast of Leadville, the southern continuation of the Gore Range, known as the Mosquito Range, is joined to the Front Range by high east-west spurs from the two mountain systems. Farther south the two ranges are separated by the broad basin of South Park (Fig. 1).

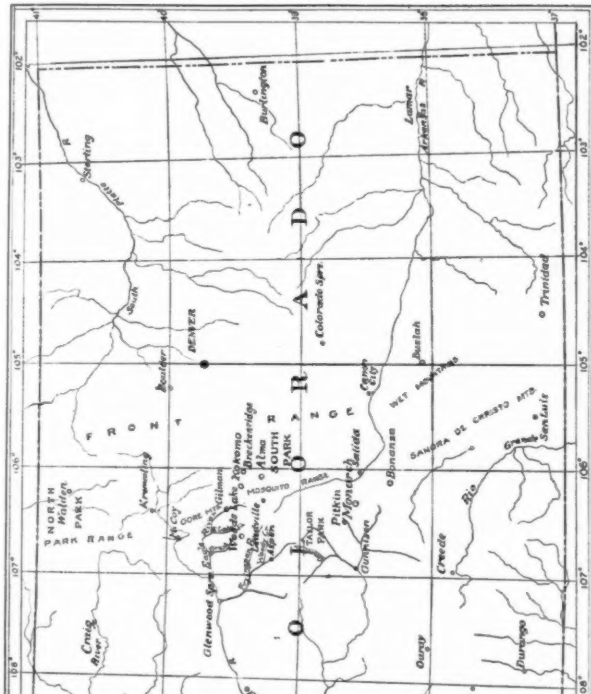

FIG. 1.—Map of Colorado showing localities discussed in this paper.

This region includes pre-Cambrian schists, gneisses, and granites; Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, Permian, Triassic, Jurassic, Lower Cretaceous, Upper Cretaceous, early Eocene, Miocene, and Pleistocene sediments; and early Eocene intrusive rocks, and Miocene intrusive and extrusive rocks. With the exception of part of the Pennsylvanian and Permian and all the Eocene, Miocene, and Pleistocene formations, the sediments are marine.

Broad areas of pre-Cambrian rocks are exposed in the Front and Sawatch ranges and a narrow belt of pre-Cambrian continues through the center of the Mosquito, Gore, and Park ranges. Paleozoic sediments border the pre-Cambrian rocks of the Mosquito Range and occur on the west side of the Gore and west of the southern part of the Park Range. Mesozoic sediments lie on the pre-Cambrian of the Park Range farther north and form the eastern border of the metamorphic rocks of both the Gore and Park ranges. Mesozoic sediments also lie on the pre-Cambrian rocks along the western border of the Front Range from the center of North Park south to Dillon. With the exception of the eastern edge of South Park, where Mesozoic sediments lie directly on the pre-Cambrian granite, Paleozoic sediments form the western border of the Front Range south of Dillon.

The Gore and Mosquito ranges are relatively narrow uplifts and in only a few places have widths of more than 10 miles. These ranges and the western part of the Front Range in the region bordering the valley of Blue River are steep or overturned asymmetric folds, broken by strike faults that have relatively dropped the southwestern side. The two largest faults of the region, the Williams Range underthrust fault on the western border of the Front Range, and the Mosquito fault on the western edge of the Mosquito and Gore ranges, have lengths of more than 50 miles. The field work of the present writers shows that both faults have displacements of more than 5,000 feet. The general structure of the sediments in this region is that of gentle, northeasterly dipping monoclines. Locally, near the mountain fronts, the beds have been involved in strong folding and faulting and dip westward at steep angles or may be overturned toward the east.

The western border of the Gore Range marks a zone characterized by great unconformities and unsystematic overlaps. Nearly all the Paleozoic formations disappear as they are followed east to this range. The lack of regularity in their disappearance indicates neither progressive nor retrogressive overlap, but rather the approach to a region that was persistently high or repeatedly uplifted. In the following descriptions of the formations, the unsystematic overlaps become more

and more apparent as the details of the unconformities between the various formations are indicated.

Table I shows the formations present and briefly summarizes their characteristics and general relations.

TABLE I

PRE-DAKOTA FORMATIONS OF CENTRAL COLORADO, THEIR THICKNESS AND GENERAL CHARACTERISTICS

		Feet	
Upper Cretaceous	Dakota sandstone		Sandstones—white to brown, with interbedded shales and sandy shales. In places quartzite
			Unconformity
	Morrison formation	0–400	Green, gray, and red shales. Sandy shales and impure limestones and limy mudstones
Jurassic			*Unconformity*
	Curtis* formation	0–40	Green and gray limy mudstones, shales and sandstone. Some oölitic limestone and sandy oölites. Contains Sundance fossils
	Entrada* sandstone	0–110	Massive, cross-bedded sandstone, light gray, salmon, or brown
			Unconformity
		0–410	Fine sandstones and mudstones. Red and purplish red. Tentatively correlated with Chinle formation*
Triassic			
		0–20	Discontinuous conglomerates, mainly of quartz pebbles. Bright red, contains silicified wood. Tentatively correlated with Shinarump conglomerate of southeastern Utah *
			Unconformity
Permian	Maroon formation	1,500 to 11,000	Sandstones, grits, and conglomerates, with interbedded shales and limestones. Locally contains thick beds of gypsum Color commonly red and red brown, but considerable amounts of gray and greenish gray sediments
Pennsylvanian	Weber formation	500 to 2,000	Gray to black sandstones, shales, and impure limestones near base, becoming coarser above. Grits and conglomerates locally abundant. Contains some red beds. Grades upward into Maroon

* These Triassic and Jurassic formations were first recognized in this region near Glenwood Springs by J. B. Reeside, Jr., and J. S. Williams and the descriptions given in this table are from their unpublished data. The present writers wish to acknowledge Mr. Reeside's kindness in pointing out to them, in the field, the lithologic distinctions of these formations.

			Unconformity
Mississippian	Leadville limestone	0 to 450, average about 150	Limestone and dolomite. Blue to lead gray, some almost black. Beds massive to thin. Nodules and streaks of black chert are locally abundant, especially in upper part. Beds are dolomites in Mosquito Range and Gilman districts, but become less dolomitic southwest. Are pure limestones around and south of Aspen. Basal bed of sand, quartzite, or limestone breccia with sand cement nearly everywhere present
	Chaffee formation		*Unconformity*
	Dyer dolomite member	0 to 350	Dolomitic limestone. Dark gray, in places light gray near base. Tends to weather to tan or brownish tint. Medium to thinly bedded. Commonly shaly or sandy at base grading into Parting below
Devonian			Sandstone, shale, calcareous shale, and impure limestones
	Parting quartzite member	40 to 125	White to green, red, or chocolate-colored. Locally a basal conglomerate. In Leadville, Alma, and Gilman areas almost entirely sandstone or quartzite, but locally has shale at base. Toward south and southwest becomes more shaly and calcareous
			Unconformity
	Fremont limestone	0 to 325	Massive, white to dark gray dolomite. Contains abundant corals
			Unconformity
Ordovician	Harding sandstone	0 to 150	Series of sandstones, shales, calcareous shales, and impure limestones, red, brown, green, and gray. Some beds contain fish fragments
	Manitou limestone	40 to 425	Thin-bedded light gray dolomite, very siliceous in places. Contains interbedded shales and sandy shales. White chert abundant as nodules and thin bands in dolomite
	Sawatch formation		
Cambrian	Peerless shale member	40 to 60	Shales, thin limestones, calcareous shales, some sandy shales and thin sandstones or quartzites. Usually an edge-wise conglomerate at top giving "red cast beds"
	Quartzite member	0 to 400	Thin to massively bedded quartzites, gray to white. Locally basal conglomerate
	Unconformity		
Pre-Cambrian	Chiefly schists, gneisses, and granites		

CAMBRIAN

The Sawatch quartzite, of Upper Cambrian age, consisting chiefly of quartzite, is one of the most widespread and persistent of the lower Paleozoic formations. The Sawatch quartzite everywhere rests on pre-Cambrian rocks, which consist chiefly of granite and highly metamorphosed schistose sediments. The surface on which the Cambrian deposits rest is remarkably even and suggests that previously the area had been subject to long-continued erosion.

About 12 miles north of McCoy, the Sawatch quartzite is very thin and disappears as it is followed north. In this region it is overlain by the Morrison formation, recently assigned to the Jurassic by the United States Geological Survey.[1] As it is followed southward, Paleozoic rocks appear between it and the Morrison formation. About 5 miles north of McCoy, there are excellent exposures in the cuts of the Denver and Salt Lake Railroad, showing the lower part of the Paleozoic section. In this region the Cambrian quartzite ranges from 100 to 125 feet thick and is overlain by about 110 feet of interbedded shale, limestone, and sandstone of Upper Cambrian age, belonging to the Peerless Shale member (2)[2] of the Sawatch quartzite. This, in turn, is overlain by erosion remnants of the lowest Ordovician formation (Manitou limestone) ranging in thickness from a thin film to about 100 feet.

On Colorado River 7 miles east of McCoy the lower Paleozoic section is exposed in a railroad cut. Here the lower part of the Sawatch quartzite is almost entirely missing and the pre-Cambrian rocks are overlain by only 10 feet of grayish green, sandy and gritty quartzite, containing white quartz pebbles $\frac{1}{2}$ inch in diameter. Above this member greenish and grayish sandstones and shale and massive gray limestone alternate for about 150 feet before the maroon and red micaceous shales of the Pennsylvanian appear. A few miles farther east, where the contact of the pre-Cambrian and the sediments can be studied, the Cambrian is entirely lacking, nor does it again appear near the western border of the Gore Range until the Tenmile district is reached, about 40 miles southwest. Here a thin erosion remnant of the Sawatch quartzite rests on pre-Cambrian rocks on the top of Little Bartlett Mountain on the east side of the Mosquito fault about 3 miles southeast of Kokomo (11). Near Alma (22), a short distance

[1] J. B. Reeside, Jr., A. A. Baker, and C. H. Dane, "Correlation of Jurassic Formations of Parts of Utah, Colorado, Arizona, and New Mexico," *U. S. Geol. Survey Prof. Paper* in process of publication.

[2] First defined by Behre in Leadville region; for parenthetical references see Bibliography at end of paper.

east, and near Leadville (12) a few miles farther south, the Cambrian has its normal position in the section. It is present throughout the Mosquito Range (16), where, however, its thickness ranges from about 85 to more than 200 feet (Fig. 2).

Farther south, in the area east of Salida, the Cambrian is very thin and is lacking in most of the Red Gulch region; only thin erosional remnants remain here and there under the younger sediments[1] (Fig. 2). Similar relations are found farther south in the Bonanza district (4).

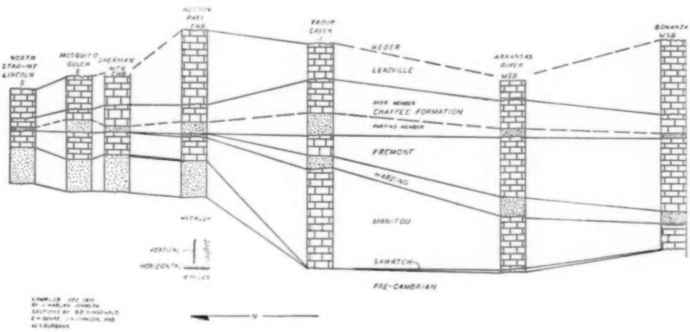

FIG. 2.—Sections from northern end of Mosquito Range through Alma and Leadville district, south to the Bonanza district.

Along Eagle River the Sawatch underlies the later sediments. While varying in thickness in each section measured, it gradually thickens toward the west and is about 350 feet thick near Glenwood Springs (Fig. 3).

South of Eagle River along the west side of the Sawatch uplift the Sawatch formation is everywhere present, but shows considerable and, in places, rapid variations in thickness. It reaches a maximum of more than 400 feet south of Aspen, but is thinner toward the south and somewhat more than 230 feet are present on Cement Creek (25) (Fig. 4). A line of sections (Fig. 5) running southeast from Glenwood Springs to the Bonanza district shows that the Cambrian deposits become progressively thinner until in the vicinity of Bonanza only isolated patches are present.

On the east side of the Front Range the Sawatch crops out only along the mountain front and in a few small basins between Cañon City and Perry Park (3). It attains a maximum thickness of 115 feet west of Colorado Springs.

[1] Unpublished data of B. S. Butler, E. N. Goddard, and J. H. Johnson.

East of Salida and east of the Front Range there is clear evidence of unconformity between the Sawatch and the Manitou, and the variations in thickness of the Peerless member of the Sawatch suggests

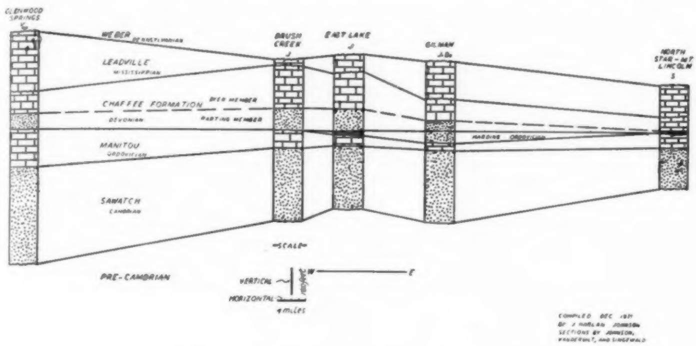

FIG. 3.—East-west series of sections extending from Glenwood Springs to the northern end of the Mosquito Range.

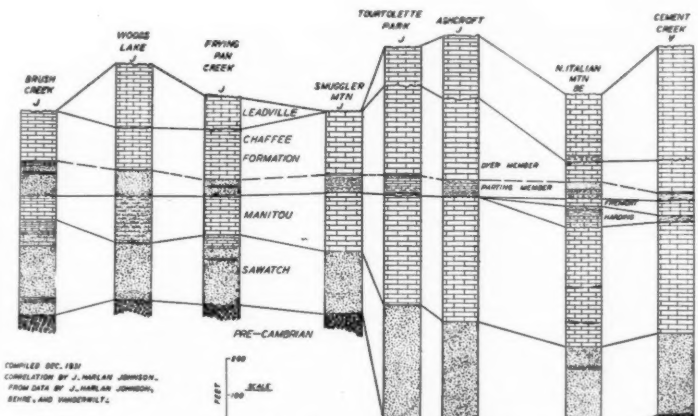

FIG. 4.—Sections extending southwest along the western side of the Sawatch Range from Brush Creek through Aspen to Ashcroft and south to Cement Creek.

that this unconformity is widespread in central Colorado, although locally the only evidence of a break in deposition is the presence of "red cast beds" or edgewise conglomerate.

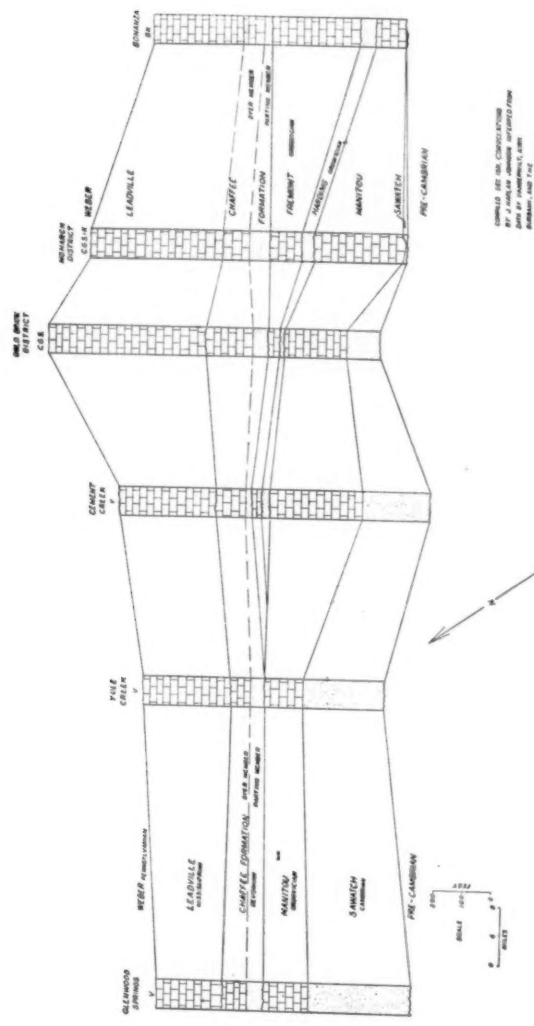

FIG. 5.—Sections extending southeast from Glenwood Springs to Bonanza district.

ORDOVICIAN

With the possible exception of the region near Salida and the Bonanza district, the Lower Ordovician (Manitou limestone)[1] on the western side of the Front Range is everywhere underlain by the Cambrian. It disappears within a few miles as it is traced north of McCoy and does not again reappear along the Gore or Front ranges in Colorado. Near McCoy it has a very uneven upper surface which is well exposed in the railroad cuts south of Hydrate Siding. Both underground and surface channels were cut in the top of this limestone before the deposition of the Pennsylvanian sediments which rest directly on the Lower Ordovician rocks in this locality. At McCoy the Sawatch quartzite is separated from the Pennsylvanian grits by only a thin bed of grayish white limestone. The upper part of the section of alternating limestone, sandstone, and shale found in the railroad cut 7 miles east of McCoy may be of Ordovician age, but no fossils were found and it is provisionally regarded as absent. Farther east both Ordovician and Cambrian rocks are missing and no Ordovician is exposed along the western side of the Gore Range between Colorado River and the Alma-Leadville mining district, where the Manitou has its normal place in the geologic column (Fig. 2). Southward along the Mosquito Range the Manitou is everywhere present but shows great variations in thickness, reaching a maximum of more than 400 feet along Trout Creek. It thins rapidly eastward and is missing in the eastern half of South Park. Southward it becomes thinner but is still represented by about 100 feet of sediments in the Bonanza district (4).

No trace of either the Harding or the Fremont formation has been found in the northern Mosquito Range, but just south of Weston Pass, a red shale containing fish fragments is present that is provisionally assigned to the Harding by Johnson (16), although regarded as part of the Devonian Parting quartzite by Behre. Farther south at Trout Creek, Manitou, Harding, and Fremont are found. The Fremont gradually thickens toward the south and reaches a thickness of about 300 feet in the Bonanza district (4).

From Gilman west to Glenwood Springs the Manitou is present, though much thinner than on the Mosquito Range (Fig. 3). It reaches a minimum of about 20 feet at Gilman but gradually thickens westward. About 45 feet of variegated beds which may be either Parting or Harding overlies the Manitou at Gilman and some similar beds were also found along East Lake Creek. Farther west definite Devonian

[1] The subdivisions of the Ordovician used in this paper are those first recognized west of the Front Range by Kirk (17).

sediments rest directly on the Manitou. No Fremont is present in any of these sections.

For a long distance southwest of Gilman and East Lake Creek, the Manitou is everywhere present (Fig. 4). It thickens steadily and reaches a maximum of nearly 400 feet a few miles south of Aspen. Farther south in the Taylor Park[1] and along Cement Creek (25), it is approximately 350 feet thick. No Harding was found between East Lake Creek and Taylor Park by the writers, but at the latter locality the Harding is well developed and some Fremont is also present. The sections shown in Figure 4 indicate that the Harding thins southward and the Fremont thickens.

Between Glenwood Springs and the Bonanza district (Fig. 5), the Manitou is everywhere present, but becomes alternately thicker and thinner, ranging from about 100 to more than 300 feet. Apparently both the Harding and the Fremont are present from Cement Creek (25, 6, 7) to Bonanza (4), and the Fremont has its maximum known thickness in the Bonanza district.

East of the Front Range Ordovician deposits crop out from the vicinity of Beulah northward to Perry Park, but are best developed in the so-called "Cañon City embayment." In this region also they show considerable and rapid variations in thickness (3).

The field evidence of unconformity between the Harding and Manitou and the Fremont and Harding, the differences in age indicated by their faunas, the variations in thickness and the appearance and disappearance of the individual formations brought out by the diagrams, all indicate that the deposition of each was preceded and followed by a period of erosion. The most marked unconformity within the Ordovician seems to be that at the base of the Harding. The erosion interval that followed the deposition of the Fremont probably included all the Silurian and some of the Devonian and gave rise to the most marked break in the older Paleozoic formations.

DEVONIAN

CHAFFEE FORMATION

The Devonian in central Colorado is represented by the Chaffee formation (18), which consists of two members, the Parting quartzite below and the Dyer dolomite above.

Parting quartzite member.[2]—The Parting quartzite member of the Chaffee formation is in most places underlain by one of the Ordovician

[1] Unpublished data from B. S. Butler and C. H. Behre, Jr.

[2] The Parting quartzite was first named by Emmons (9), and was later made a member of the Devonian Chaffee formation by Kirk (18), largely as a result of field work in the Leadville district by Behre (1) (2).

formations. In the region bordering the Gore Range between Colorado River and Leadville it is very siliceous. Here it is predominantly quartzite, but contains some interbedded shales and sandstones. Near Gilman and farther north the base of the Parting is marked by white quartz pebble conglomerate. As it is followed west and southwest from Minturn it changes in character and becomes much more shaly and less siliceous, and in the region near Aspen there are little or no sandstone and quartzite present at this horizon. Farther west, near Marble, the Chaffee formation is largely limestone and shale and has only a little sandy material at the base (25).

At two places on the eastern side of the Mosquito fault, 9 miles east and 8 miles northeast of Minturn respectively, remnants of the Paleozoic sediments resting on the pre-Cambrian rocks occur on the upthrown side of the fault. At both places the basal member of the series is a thin discontinuous quartzite whose contact with the pre-Cambrian granite is marked by a bed of white quartz pebble conglomerate identical in appearance with the basal Parting of this region, and the conglomerate is correlated with it by the writers. The overlying Dyer and Leadville limestones, as well as the Cambrian and Ordovician limestones, are absent at these two localities, and the Parting quartzite is overlain by Pennsylvanian grits, shales, and limestones. The Parting quartzite has not been recognized farther north in the region bordering the Gore and Park ranges.

Singewald (23) reports the absence of the Parting at some points within the Alma district, and its thickness is variable in the area adjoining. Northwest, west, and south of Alma, however, it is present in all the sections measured, though it shows considerable variation in thickness (Fig. 3 and Fig. 4). In the region between Gilman and Cement Creek, the sediments become less sandy, more shaly, and slightly calcareous. Brainerd (3) believes that similar Devonian sediments are present east of the Front Range from Beulah to a point about 5 miles north of Cañon City and also in the region west and northwest of Colorado Springs.

The lithology of the Parting and the great differences in age of the formations that it rests upon indicate the marked unconformity at its base. There is no evidence of an erosion interval between its deposition and that of the overlying Dyer, however.

Dyer dolomite member.[1]—The Dyer dolomite member formerly known as the lower part of the "Blue" or Leadville limestone, has a

[1] The Dyer was first defined by Kirk (8), although previously recognized as a distinct and separable member of the Leadville limestone of Emmons, first by Crawford and Gibson (8) in the Gilman region, and later by Behre in the Leadville district (1).

fairly uniform character throughout wide areas, although its thickness is different in each section measured. Along the Mosquito Range it varies from a few feet to more than 150 feet, and is thickest between Weston Pass and Salida. As shown in Figure 3, it shows even greater variations as it is followed west to Glenwood Springs. It is commonly thicker southwest of Gilman than along the Mosquito Range, and reaches its maximum thickness of approximately 275 feet in the southern part of the Aspen district. It is present in each section between Glenwood Springs and the Bonanza district. Although early work by Crawford (5, 6) indicated an abnormally thick Devonian section in the Goldbrick and Monarch districts, later work by Kirk (18) shows that its thickness is probably about the same as that found in the surrounding region (Fig. 5).

In the regions examined by the writers, the Dyer is everywhere underlain by the Parting and nearly everywhere overlain by the Leadville limestone as now restricted to the Mississippian part of the beds formerly called Leadville or "Blue" limestone. The writers have traced the Parting and Dyer members only as far south as the northern part of Taylor Park, and in the region on the south and southeast not studied by them the two members have not been differentiated by other workers. The marked change in lithology noted as the Chaffee formation was traced from Gilman to Taylor Park suggests that the shaly basal Devonian farther south can be correlated with the Parting quartzite member at Gilman and Leadville. It is probable that the Pennsylvanian grits rest directly on the Dyer dolomite in some places, but in the regions where good exposures of the contacts are available there is commonly at least a thin film of the Mississippian limestone present. Nevertheless, it is almost certain that the Mississippian Leadville limestone is not present above the Dyer member of the Chaffee formation northeast of Aspen in the region lying between Roaring Fork and Woody Creek or on Brush Creek at Fulford Caves where only 10 feet of possibly Mississippian limestone was found.

It is believed that much of the variation in thickness of the Devonian is the result of erosion during the time interval before the deposition of the Mississippian (Leadville) sediments. This conclusion agrees with that of Kirk (8) as to the presence of an unconformity within the Devonian-Mississippian succession.

MISSISSIPPIAN[1]

The Mississippian Leadville limestone bore the brunt of the attack of the late Mississippian-early Pennsylvanian erosion, and as a

[1] The Leadville limestone is used in the restricted sense first given it by Kirk (18).

result is very irregular in thickness and is missing in some places. Thus, along the Mosquito Range the thickness ranges from more than 300 feet at Weston Pass (2) to less than 50 feet in parts of the Alma district (22). Toward the west similar variations occur as shown in Figure 3. South of Gilman the formation steadily becomes thinner until it almost disappears along Brush Creek near Fulford Caves. A thickness of more than 170 feet is present near Woods Lake and a considerable amount is present along Frying Pan River, yet it is absent between Woody Creek and Aspen. South of Aspen the Leadville steadily thickens until more than 300 feet is present on Cement Creek (25). Southeast of Glenwood Springs the Leadville is more than 250 feet thick in every section. It gradually thickens toward the south (Fig. 5). It is everywhere underlain by the Dyer member of the Devonian Chaffee formation and is everywhere overlain by Pennsylvanian rocks. Neither the Devonian Dyer member nor the Mississippian Leadville limestone has been found by the writers in the region bordering the western edge of the Gore and Park ranges north of Minturn.

A thin band of Mississippian limestone is present on the east flank of the Wet Mountains between Beulah and Cañon City. It occurs again in the region west of Colorado Springs and at the southern end of Perry Park (3). No outcrops are known farther north along the Front Range, but the conglomerates of the Pennsylvanian and younger formations contain pebbles that carry Mississippian fossils, suggesting the former presence of Mississippian deposits in that area.

The unconformity at the base of the Leadville limestone is conspicuous near the western side of the Gore and in the northern part of the Mosquito Range, where its base is marked by sandstones or quartzites commonly interbedded with a breccia of limestone and chert fragments. As it is followed southwest the unconformity is somewhat less evident, though in all sections examined by the writers the base of the Leadville is marked by limestone breccia. Although the breccia has a sandy matrix in the region south of Aspen, definite sandstones or quartzites are lacking.

PENNSYLVANIAN

Pennsylvanian shales and grits in most places grade upward into the overlying Permian shales and grits and it is difficult to draw a line between these two series at the present time. A study of the fossil plants by David White has indicated the approximate limits of the Pennsylvanian rocks. In most places they are about 2,000 feet thick. The colors of the Pennsylvanian vary from place to place. The section, which is in general gray or brown south and southeast of Leadville,

becomes more reddish as it is traced toward the north. Near Minturn is a thickness of several hundred feet of maroon material of undoubted Pennsylvanian age, and in the region around McCoy nearly the whole section is red, although it is a more purplish red than is common in the Permian section. The Pennsylvanian in the McCoy region resembles the Pennsylvanian Fountain formation on the eastern side of the Front Range.

The Pennsylvanian lies unconformably on the older rocks and overlaps them toward the north near McCoy and toward the east in the region between McCoy and Alma. It rests upon the Ordovician and Cambrian northeast of McCoy, upon the Devonian Parting quartzite on the eastern side of the Mosquito fault east and northeast of Minturn, and on the Mississippian Leadville limestone and the Devonian Dyer dolomite in the region between Minturn and Aspen.

Ten miles east of McCoy, Pennsylvanian grits overlap the Ordovician and Cambrian rocks and rest directly on pre-Cambrian schist. The Pennsylvanian grits in this locality do not exceed 300 feet in thickness, although near McCoy they have a thickness of approximately 1,800 feet. Pennsylvanian rocks have not been found more than 8 miles north of McCoy in the region bordering the western side of the Gore and Park ranges and have not been found between the Front Range and the Park Range systems north of Breckenridge (20, 21) except in the northernmost part of the state. As the beds are followed southeast along the western border of the Gore Range, there is no place where both the top and the bottom of the Pennsylvanian are exposed, but in the erosion remnant east of the Mosquito fault 8 miles east of Minturn, 600 feet of Pennsylvanian is present. On Gore Creek 2 miles due north of Minturn there is locally an angular unconformity between beds containing the Pennsylvanian flora and those containing a Permian flora. Pennsylvanian beds are present in the valley of Blue River 5 miles south of Breckenridge (14), but are absent at Breckenridge where the Permian lies directly on the pre-Cambrian schists and gneisses (21). Farther south in the region near Alma and Leadville, the Pennsylvanian has its normal position in the sequence wherever it can be studied, and the sections measured indicate thicknesses up to 1,800 feet in some localities (16). It continues southward through the region east of Salida, and along the east flank of the Sangre de Cristo Mountains into New Mexico (15).

Pennsylvanian sediments crop out at a number of localities between Minturn and Glenwood Springs, and on the northern and western border of the Sawatch uplift between Gilman and Taylor Park. In the few places where the Pennsylvanian was measured, it ranged

from 800 to 1,200 feet thick. It is also present west of Taylor Park in the Crested Butte Quadrangle (10), and Burbank (4) found it well developed in the Bonanza district.

The unconformity at the base of the Pennsylvanian is the most conspicuous one in the Paleozoic of central Colorado. Not only were large amounts of the Leadville limestone removed in large areas, but the surface on which the Weber (?) formation was laid down was locally very irregular and pitted with sink holes, solution basins, and caverns. This is beautifully illustrated in the mine workings at Gilman and Aspen. Above McCoy, a cross section of an old cavern filled with Pennsylvanian deposits is well exposed in a railroad cut. Brainerd found several similar occurrences near Beulah on the east side of the Wet Mountains.

PERMIAN AND POST-PERMIAN

The thick series of maroon, red, and gray grits, shales, and sandstones, and gray limestones that overlie the Pennsylvanian rocks, ranges in thickness from less than 100 feet to more than 9,000 feet. In most places the Permian is underlain by Pennsylvanian grits and shales, but locally rests on pre-Cambrian rocks. It is probable that the upper brick-red shale near McCoy grades laterally into the gypsiferous rocks of Permian age on the south, but no fossils were found in this part of the McCoy section. The underlying beds contain a Pennsylvanian flora and fauna. If the Permian is present in this region, it is probably not more than a few hundred feet thick. West of Minturn and south of McCoy the lower part of the Permian series is very gypsiferous, but this type of sediment is not found north and east of McCoy or east and south of Minturn.

At State Bridge, 4 miles southeast of McCoy, the Permian beds lie beneath Triassic mud shales that are probably of Chinle age, according to J. B. Reeside,[1] and the two are locally separated by a conglomerate of white quartz pebbles of Shinarump aspect containing petrified wood. On Colorado River, 7 miles northeast of State Bridge and approximately the same distance east-northeast of McCoy, the Permian Red-beds are overlain by the Jurassic Entrada sandstone, and a few miles farther northeast the Permian is overlain by the Jurassic Morrison formation. On Colorado River, 11 miles west of McCoy, there is a distinct angular unconformity between the Entrada and the underlying Permian Red-beds.

For many miles southeast of Colorado River along the western front of the Gore Range, the contact of the Permian and the overlying

[1] Oral communication.

formations is well exposed. Close to the Mosquito fault it is overlain by the Morrison formation at least as far south as a locality about 15 miles southeast of McCoy and approximately 11 miles north-northeast of Minturn. A few miles farther west the Entrada sandstone and the Triassic mud shales intervene between the Morrison and the Permian. Near Breckenridge the Permian red shales are only about 700 feet thick and rest directly on the pre-Cambrian schists and granite. Ten miles farther south they are nearly 5,000 feet thick and overlie the Pennsylvanian shales, but at Georgia Pass, 6½ miles east of Breckenridge, the Permian and all older formations are missing and the Dakota quartzite rests on pre-Cambrian gneiss (19). Permian Red-beds underlie the Morrison a few miles east of Dillon, but the Dakota quartzite apparently rests directly on the pre-Cambrian schist a few miles farther west and southwest. Exposures in this region are not good, however. In the region southeast of Alma along the western side of the Front Range the Permian is everywhere overlain by the Morrison formation.

As already mentioned, there are local angular unconformities at the base of the Permian, about 2 miles north of Minturn.

The colors of the Permian beds vary in different localities. The Permian is uniformly gray or greenish gray where it is gypsiferous and is in general maroon south and southeast of the gypsiferous basin. Toward the north it is red or orange-red and approximates the color of the overlying Triassic formation. This is also the color of the upper part of the Permian section south of the gypsum basin in the region near Aspen.

Summary and Conclusions

UNCONFORMITIES

It is believed that the foregoing evidence shows that unconformities are the cause of many and, in places, of abrupt variations in thickness of the Paleozoic formations. Changes in thickness due to differences in deposition are also suggested. Unconformities probably cause the different thicknesses of the Manitou limestone. The occurrence of patches of the Ordovician Harding sandstone at Gilman and along East Lake Creek, and the fact that that formation is best developed in the southeastern point of the area and wedges out under unconformities toward the north and northwest, strongly suggest that the formation was originally much more widely distributed than the Devonian rocks. This is also true of the Fremont limestone. A study of the sections shown in Figures 3, 4, and 5, suggests that erosion removed large but varying amounts of the Dyer before the deposition

of the Mississippian Leadville. Field evidence clearly indicates that after the Leadville was deposited the region was uplifted and subjected to long continued erosion before the beginning of Pennsylvanian deposition.

Of the several unconformities present within the Paleozoic, the one under the Devonian deposits represents the greatest amount of time, as it includes the latter part of the Ordovician, all the Silurian, and part of the Devonian periods. The diastrophism which caused it was probably related to the important late Ordovician disturbances in Oklahoma and possibly included some warping and minor uplift in the southern part of the Front Range area. During the early Paleozoic there was probably a rather wide channel or arm extending from the central Colorado depositional basin across the end of the present Front Range area into the present Cañon City basin. It is believed that during the Ordovician it extended across southeastern Colorado and connected with the depositional basin of northern Oklahoma. This channel was restricted by an uplift of the Front Range land mass before the beginning of the Pennsylvanian deposition (probably during the later half of the Mississippian) and may have been similarly affected by the movements during the Ordovician.

The unconformity beneath the Pennsylvanian is the one whose effects are best known to geological literature. It represents in time the upper half of the Mississippian and in places at least some of the lower Pennsylvanian. During this interval widespread denudation occurred, preceded in all probability by important movements in the Front Range, Wet Mountain, and Uncompahgre highlands.

The variations in thickness of the Pennsylvanian and Permian formations are clearly in part the result of unconformities, but original differences in deposition undoubtedly caused much of the variation observed at a distance from the zone of overlaps that follows the western border of the Gore Range.

The only connecting transitional beds occur between the Parting and Dyer members of the Chaffee formation (Devonian), and in most places between the Peerless member of the Sawatch quartzite and the overlying Manitou limestone.

FRONT RANGE HIGHLAND

The sections and unconformities which have been discussed add considerably to the existing information on the Front Range Highland (15, 19, 26). The new facts may be summarized as follows.

There is a general tendency for all beds earlier than Upper Cretaceous to thin or disappear as they are traced eastward toward the

Gore and Front ranges. Here, in a narrow northwesterly trending zone of irregular overlaps, the unconformities that are not especially conspicuous between the various Paleozoic formations on the southwest abruptly become very marked. The formations do not drop out in orderly succession as they would if their disappearance were caused either by one period of tilting, truncation, and succeeding sedimentation, or by the continuous downwarping of a region of sedimentation. These accentuated unconformities consistently repeated in a narrow zone are believed to be conclusive field evidence for the persistence of an oscillating highland on the northeast. The shoaling of many of the seas in this direction is also indicated by the lateral change in the lithology of some of the formations, especially well shown by the Parting member of the Chaffee formation and by the basal beds of the Leadville limestone. The unsystematic relations of the overlaps are summarized in the following paragraph.

As the formations are traced north from the region near McCoy, they disappear in approximately the following order: Mississippian, Devonian, Triassic, Jurassic, Permian, Ordovician, Pennsylvanian, Cambrian. Southeast of McCoy the formations disappear in the following order: Mississippian, Devonian, Triassic, Ordovician, Cambrian (lower part of Sawatch quartzite and Peerless member of the Sawatch), Jurassic, Pennsylvanian, Permian, and Jurassic (Morrison formation). As the beds are followed northeast from Gilman toward the Mosquito Range they probably disappear in approximately the following order: Mississippian, Devonian (Dyer), Ordovician, Cambrian, Devonian (Parting quartzite), Pennsylvanian, and Permian. North and northeast of Alma they disappear in approximately the following order: Mississippian, Devonian, Ordovician, Cambrian, Pennsylvanian, Permian, Upper Jurassic (Morrison), and probably the lower part of the Upper Cretaceous Dakota quartzite. Along the eastern side of the range similar relations exist. In the northern part of the Colorado Springs Quadrangle sediments overlap the pre-Cambrian in the following order: Cambrian, Lower Ordovician, Mississippian, Pennsylvanian, Tertiary. In the Castle Rock quadrangle the same sequence is found in Perry Park. From there to the Wyoming line, Pennsylvanian sediments overlap the pre-Cambrian.

The foregoing facts indicate the existence of a persistent land mass in the Front Range region during all of the Paleozoic era and much of the Mesozoic era. It is apparent that this land mass oscillated and was much higher in some periods than in others. The most widespread period of denudation apparently occurred during the later half of the Mississippian epoch and very early in Pennsylvanian time. The char-

acter of the Pennsylvanian and Permian sediments indicates that a marked uplift of the ancient highland occurred during the period of denudation that preceded their deposition, and that uplift of the Front Range Highland continued concomitantly with downwarping of the basin at the west throughout Pennsylvanian and part of Permian time. The material supplied from the pre-Cambrian rocks in the highlands buried the surrounding sediments to a considerable depth. Uplift and minor erosion of the Front Range Highland probably occurred also at the ends of Ordovician, Devonian, Triassic, and Jurassic time before the deposition of sediments of the succeeding period. The evidence available indicates that this high area persisted until the close of Dakota time, but that it was completely submerged by the Upper Cretaceous sea.

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PRE-PENNSYLVANIAN STRATIGRAPHY OF FRONT RANGE IN COLORADO[1]

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ABSTRACT

This paper is a review of the pre-Pennsylvanian stratigraphy of the Front Range in Colorado.

The Cambro-Ordovician Manitou formation, as originally described, has been subdivided into a restricted Manitou of Cambro-Ordovician age, a Devonian member herein called the Williams Canyon limestone, and the Madison of Mississippian age. The term Millsap has been eliminated as a term for the lower Mississippian. A more complete description of the various unconformities is given.

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INTRODUCTION

This paper is based on field work done in 1927 and 1928 for the Marland Oil Company of Colorado by A. E. Brainerd and Harry L. Baldwin, Jr., with the assistance of I. A. Keyte, paleontologist.

The differences between earlier findings of the writers and published works necessitated careful study of the pre-Pennsylvanian Paleozoic section along the Colorado Front Range in order that accurate correlations and comparisons could be made with other sections in the western United States. Accordingly, detailed sections were measured and fossil collections made at as many localities as possible. As identification of the fossils has not been completed, this paper is based principally on lithologic correlations in conjunction with published paleontologic data.

A great amount of work was done in this area at an earlier date by the Hayden and other surveys, and their work has been published in the reports of the United States Geographic and Geologic Survey of the Territories. Many detailed sections were measured, but corre-

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lations were made from very limited paleontologic evidence. Many unconformities were not recognized, and beds have been grouped together from lithologic similarity which can be seen after careful examination to be separated by erosional unconformities. For a bibliography of these and other early reports, reference is made to United States Geological Survey Professional Paper 16, "Carboniferous Formations and Faunas of Colorado," by George H. Girty, which lists all the early publications on this area, and gives a discussion of all sections and the authors' interpretations of the correlations. The writers of this paper take exception to many of these correlations, but since a complete discussion of individual cases would be entirely too long for the present paper, it has been limited to only the latest publications on each portion of the Front Range.

The writers have made a number of changes in the earlier correlations, the most important of which is the division of the Manitou as defined in the Colorado Springs folio into a restricted Manitou of Beekmantown age, the Williams Canyon limestone probably of Devonian age, and the Madison limestone of Mississippian age. A new formation, the Williams Canyon limestone, which can not readily be grouped with any former subdivision, is herein introduced for a series of thin-bedded limestones and calcareous shales typically exposed in Williams Canyon at Manitou Springs. These beds are probably of Devonian age and equivalent to the Parting quartzite of the Western Slope in Colorado.

The pre-Pennsylvanian Paleozoic rocks range in age from Cambrian to Mississippian, and are best exposed in the Cañon City embayment, with isolated exposures in a narrow band extending from Beulah, 25 miles southwest of Pueblo, to Perry Park, 10 miles southwest of Castle Rock. North and south of these limits, beds of Pennsylvanian age rest on the pre-Cambrian, with the older Paleozoic rocks missing as a result of either non-deposition or erosion. In a considerable part of this area the older Paleozoic beds are concealed by faulting and overlap of younger beds. A number of sections were also measured in central Colorado west of the Front Range, one of which, as exposed along Arkansas River about 5 miles below Salida, is given for comparison.

Table I summarizes the conclusions of the various workers on the pre-Pennsylvanian beds along the Colorado Front Range.

GENERAL STRATIGRAPHY

PRE-CAMBRIAN

In the vicinity of Colorado Springs and farther north the Cambrian Sawatch sandstone rests on the Pikes Peak granite. In the

Cañon City area and farther south, highly folded gneisses, schists, and quartzites form the basement rocks. Where the Sawatch is present, the contact is nearly everywhere a remarkably smooth plane of erosion, and where it is missing there are generally irregularities of several feet in short distances in the pre-Cambrian, as shown by the illustrations. This suggests the possibility that the absence of the Sawatch in sections near Cañon City and on the south is due to post-Sawatch and pre-Manitou erosion rather than non-deposition.

TABLE I

COMPARATIVE TABLES OF PRE-PENNSYLVANIAN ALONG COLORADO FRONT RANGE

	Cross *Pikes Peak Folio U.S.G.S. 1894*	*Gilbert* *Pueblo Folio U.S.G.S. 1897*	*Darton* *Professional Paper 32 U.S.G.S. 1905*	*Richardson* *Castle Rock Folio U.S.G.S. 1915*	*Finlay* *Colo. Springs Folio U.S.G.S. 1916*	*Present Paper* —
Pennsylvanian	Fountain					
Mississippian	Millsap	Millsap	Millsap	Millsap	None	Madison
Devonian	None	None	None	None	None	Williams Canyon
Silurian	None	None	None	None	None	None
Ordovician	Fremont Harding Manitou	Harding	Fremont Harding Manitou	Manitou	(Harding) Manitou	Fremont Harding Manitou
Cambrian	Cambrian		Reddish sandstone	Sawatch	Sawatch	Sawatch

CAMBRIAN-SAWATCH

The oldest Paleozoic formation in the Colorado Front Range is the Sawatch sandstone, the type locality of which is in the Sawatch Mountains of central Colorado. It was named and described by Eldridge,[1] although it had been previously mentioned by Cross[2] as "Quartzites lying beneath the Manitou limestone in Manitou Park at Manitou Springs."

Exposures of the Sawatch along the Front Range are limited to Manitou Springs and northward, although it is possible that remnants may occur south of Manitou Springs. It is an even-grained, well-

[1] G. H. Eldridge, *U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte Folio 9* (1894), p. 6.

[2] Whitman Cross, *U. S. Geol. Survey Geol. Atlas, Pikes Peak Folio 7* (1894), p. 1.

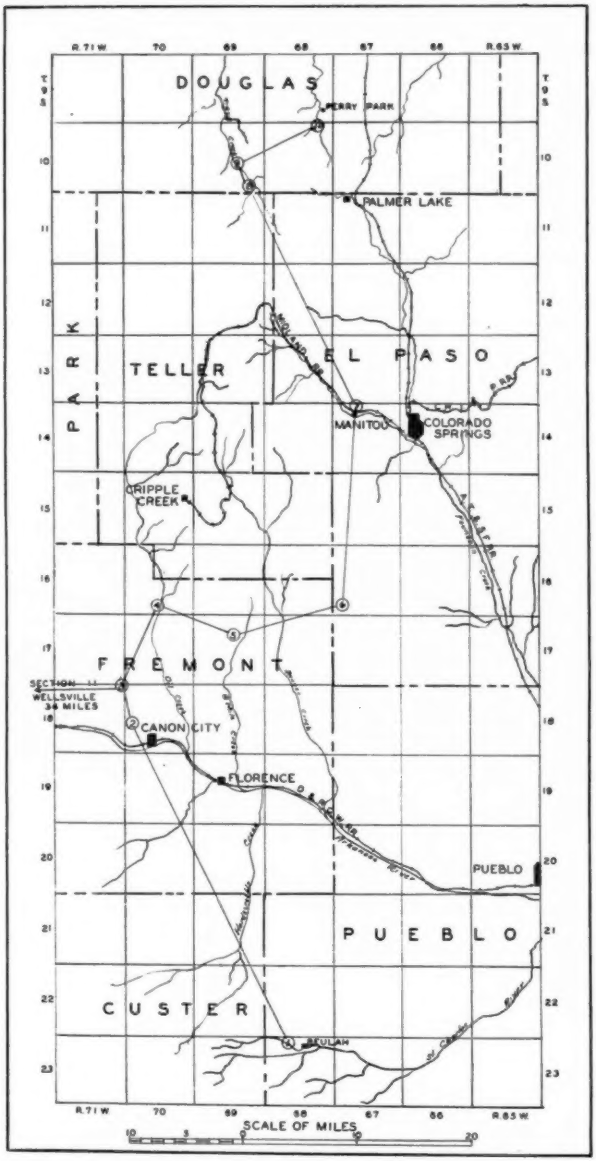

Fig. 1.—Index map showing location of measured sections. Numbers in small connected circles correspond with numbers on cross section, Figure 9. Town of Wellsville, Figure 10, is 3 miles north and 35 miles west of Cañon City.

bedded, quartz sandstone, locally a quartzite, slightly arkosic in the lower part, and with a quartz-pebble conglomerate as the basal member at some localities. Some beds contain many large, well-rounded quartz grains in a fine even-grained matrix. Glauconite is rather common in the lower and upper parts. Some beds near the top are quite calcareous. The color varies from white and light gray to a distinct red. The maximum thickness of slightly more than 100 feet is reached in Perry Park, and decreases southward to about 45 feet in Williams Canyon near Manitou Springs. It was probably deposited over the entire area but partly removed by later erosion.

FIG. 2.—Sawatch sandstone resting on smooth granite surface. Manitou Park.

Its age has been placed as upper Cambrian by the United States Geological Survey[1] on the basis of the few fossils that have been found. This suggests a correlation with the Ignacio quartzite of southwestern Colorado, the Reagan sandstone of Oklahoma, the Bliss sandstone of the Franklin Mountains of West Texas, and part of the Deadwood formation of Wyoming, all of which are similar lithologically.

CAMBRO-ORDOVICIAN

Manitou limestone.—The measured sections and fossil collections which form the basis of this paper show beyond doubt that a considerable part of what has been called the Manitou limestone in the Colo-

[1] *U. S. Geol. Survey Geol. Atlas, Pikes Peak Folio* 7, p. 2.

rado Springs[1] and Castle Rock[2] quadrangles is of younger age. The original description is therefore very important in order that it may be determined if these younger beds were included or have been erroneously added by later geologists.

The only reference which the authors have been able to find to the original description of the Manitou is that given in the Pikes Peak Folio,[3] which states:

> The Silurian section of upturned zone between Cañon City and Garden Park has been studied in detail by Mr. C. D. Walcott, and divided into three important formations, distinguishable by their rich invertebrate faunas and also by stratigraphic data, to which he has given the names here used,

with a reference to C. D. Walcott.[4] Examinations of Walcott's paper have failed to give any clue to the type locality, or a detailed section which would give the limits of the formation.

The same folio later states:

> In Garden Park it consists of fine-grained pink or reddish dolomite less than 100 feet thick and contains *Ophileta*, *Camerella* and a few other invertebrate fossils characteristic of the lower Silurian formations in the section at Manitou Springs and in Manitou Park, whence the name is derived.[5]

The Colorado Springs Folio[6] states, "The Manitou limestone is named from Manitou Springs, where it is typically developed." It is therefore doubtful which of these two localities, Manitou Springs or Manitou Park, which are about 20 miles apart, is the type locality.

The importance of having a type section in which the upper and lower limits are definitely established, and the need for re-defining this formation, has led the writers to submit the following section, which is very well exposed in the Narrows of Williams Canyon near Manitou Springs, as representative of the type section, in which the name Manitou is restricted to the Ordovician limestone lying between the Cambrian Sawatch sandstone and the Devonian limestone.

In this section the Manitou appears to rest conformably on the Sawatch sandstone with a gradational change from sand to sandy limestone to limestone. In other localities there appears to be an un-

[1] George I. Finlay, *U. S. Geol. Survey Geol. Atlas, Colorado Springs Folio 203* (1916), p. 6.

[2] G. B. Richardson, *U. S. Geol. Survey Geol. Atlas, Castle Rock Folio 198* (1915), p. 4.

[3] *U. S. Geol. Survey Geol. Atlas, Pikes Peak Folio 7*, p. 2.

[4] C. D. Walcott, "Preliminary Notes on the Discovery of a Vertebrate Fauna in Silurian (Ordovician) Strata," *Geol. Soc. Amer.*, Vol. 3 (1892), pp. 153–73.

[5] *U. S. Geol. Survey Geol. Atlas, Pikes Peak Folio 7*, p. 2.

[6] P. 6.

conformity. The irregularity of the Manitou contact on the pre-Cambrian as contrasted with the almost perfect plane which characterizes the Sawatch-pre-Cambrian contact, suggests an intervening period of erosion which removed the Sawatch over a large area and left minor irregularities on the surface of the pre-Cambrian.

TABLE II

WILLIAMS CANYON SECTION, EL PASO COUNTY, COLORADO

Measured on east side canyon above the "Narrows," north of Manitou. SW. $\frac{1}{4}$, Sec. 32, T. 13 S., R. 67 W.

PENNSYLVANIAN

Fountain Formation

15 Shale, red and arkose sandstones

Unconformity

MISSISSIPPIAN

Madison Limestone

14 Limestone, light gray, very dense, massive. Contains much brecciated material which has filled solution cavities, partly derived from Fountain formation. Thickness varies because of erosion of upper part. About.... 100 feet

Unconformity

(Several feet missing from top of formation below in distance of 20 feet horizontally)

DEVONIAN

Williams Canyon Limestone (Type Section)

13	Sandstone, fine grained with many coarse grains up to 1 mm. Fragments of limestone up to several inches at top	Fraction of inch to 2 feet
12	Limestone, massive, weathering irregularly, light gray weathering gray and light buff. Sand in lenses, with grains of all sizes and shapes	2 feet
11	Shale, calcareous, light brown	3 inches
10	Limestone, light gray, fine grained	3 inches
9	Shale, calcareous, light brown	3 inches
8	Limestone, sandy, light gray weathering buff. Sand grains of all sizes	1 foot
7	Limestone, thin bedded, gray, weathering light gray and buff. Thin breaks of light brown shale, and occasional layers of sandstone and sandy limestone, fine and coarse grains. Poorly exposed	15 feet
6	Limestone, dark gray weathering buff, dense	1 foot
5	Conglomeratic limestone, light gray, with small pebbles of quartz and chert (maximum diameter, $\frac{1}{4}$ inch)	6 inches
4	Sandstone, very fine grained, with small pebbles of limestone, gray	2 inches to 4 feet
	Thickness of Williams Canyon limestone,	25 feet

Unconformity

(Indicated by absence of usual succession)

ORDOVICIAN

Manitou Limestone

3 Limestone, dolomitic, light gray to buff at top, brown at base, weathering sandy. Upper part massive, lower part weathers thin-bedded and nodular and contains considerable chert. Fossils about 5 feet above base, with few poorly preserved gastropods in upper part.... 218 feet

UPPER CAMBRIAN

Sawatch Sandstone

2 Sandstone, white, red, and reddish brown. Fine to coarse, with many coarse grains and some small quartz pebbles in lower part. Glauconitic in upper part.... 45 feet

Unconformity

PRE-CAMBRIAN

1 Granite, coarsely crystalline. Upper surface practically plane

The Manitou consists of a well-bedded, reddish gray to gray magnesian limestone, with local thin beds of chert. Its maximum thickness along the Front Range is 218 feet at Williams Canyon, but decreases southwest to a thin wedge at Priest Canyon, near Cañon City, and farther south it is entirely missing. In the Arkansas River section below Salida it has a thickness of 162 feet, and 314 feet is exposed along Trout Creek in Sec. 34, T. 13 S., R. 77 W., Chaffee County, Colorado. A detailed study of the fossiliferous horizons may prove that part of the variation in thickness is due to overlap rather than to erosion of the top.

FIG. 3.—Manitou in suggested type section at Manitou Springs. Location is just above narrows in Williams Canyon. Williams Canyon limestone is shown on bench and Madison limestone forms upper cliff.

Fossils are fairly abundant at some localities, and indicate Beekmantown,[1] or Lower Ozarkian[2] age. This makes it the equivalent of a part of the Arbuckle limestone of Oklahoma, the El Paso limestone of the Franklin Mountains of West Texas, the Pogonip of Nevada, and possibly the upper part of the Deadwood formation of Wyoming and Montana.

ORDOVICIAN

Harding sandstone.—The Harding sandstone was named and described by Walcott[3] from Harding's Quarry near Cañon City. As the

[1] George L. Finlay, *op. cit.*, p. 6.

[2] C. E. Resser, personal communication to I. A. Keyte.

[3] C. D. Walcott, *Bull. Geol. Soc. Amer.*, Vol. 3 (1892), pp. 153–77.

original description and detailed section have long been out of print, they are quoted in full as Table III.

TABLE III

THE HARDING QUARRY SECTION

The Section begins near a spring a little way west of the Harding sandstone quarry, and is carried on the strike of the beds so that it terminates nearly a mile north of the quarry. This is done in order to secure contacts from layer to layer all the way from the base to the summit. The basal bed of sandstone rests unconformably upon Algonkian bedded gneiss and micaceous schists that dip to the eastward at high angles, 60–75°. The succession is as follows:

Base of Section	*Feet*	
1. *a.* Coarse, light gray sandstone	5	
b. Compact, thinly bedded reddish and gray sandstone passing into a gray and more massively bedded somewhat friable sandstone that changes, at 25 feet up, into a purplish-tinted, somewhat coarse friable sandstone (strike, N. 10° E. (mag.); dip, 40° E.)	33	
Fossils. A few scattered fish scales were noticed in the purple beds and *Lingula attenuata*, Salter (?), 20 feet from the base.		
The beds are penetrated by an immense number of annelid borings, and the surfaces of the purplish-tinted layers are often a network of the casts of the borings. On the southern side of the Arkansas River, two miles south of the section, there were found in a stratum 20 feet above the Algonkian rocks numerous fragments of the plates and scales of placoganoid fishes.		
c. Reddish brown sandy shales that are partially calcareous in some layers		
Fossils. Fish plates in great abundance and, in the calcareous layers, *Orthoceras multicameratum*, Hall (?) *Beyrichia* (like *B. fabulites*, Conrad), and several species of lamellibranchs (see list page 158)		
d. Massively bedded gray and reddish sandstone, with thin irregular beds of reddish brown sandy shale in the lower portion	20	
Fossils. Fish plates and scales of fish are numerous in the lower portion and also in a reddish brown capping of the massive bed in which the Harding quarry is located. The supposed chordal sheaths occur scattered through this bed and also more rarely in *b*, *c*, and *e*.		
e. Fine-grained argillaceo-arenaceous shale	3	
Gray and buff sandstone	7	10
f. Coarse purplish-tinted sandstone in several layers, with gray layers above		
Fossils. Plates and scales of fish		
Total sandstone	86	

Observations on the Harding sandstone series.—The lower bed is a shoreline deposit following the advance of the sea upon the land; it is formed of coarse grains of quartz and small quartz pebbles imbedded in a fine arenaceous matrix. The succeeding layers of sandstone have more or less calcareous matter in the matrix. Their continued acephalous shell, driftworn plates and scales of fishes, and the vast number of casts of annelid borings, all prove the littoral origin of the sediments. The fish plates and scales are scattered more or less throughout the beds, but they are very abundant in four principal zones, viz.—*c* of the section; near the base, and again near the summit at *d*; and at the summit of *e*. In *c* they are commingled with remains of *Orthoceras* and with acephalous mollusks and gastropods. The closing deposit of the sandstone series is formed of a coarse drifted sand, containing numerous fragments of larger fish plates than those below. The change to the succeeding shaly beds is abrupt, and apparently due to the deepening of the water and the cessation of arenaceous deposits.

The Harding Quarry section of the writers shows a greater thickness and a higher proportion of shale. The fossiliferous shale, *c*, of

Walcott's section, is believed to be continuous, and was found in all of the Front Range sections with an average thickness of 25 feet. Another shale, *e*, which may be continuous, occurs above, and a number of shales are found in the lower part which may be lenticular. The average section shows from 30 to 50 percent of shale. It rests unconformably on the Manitou or the pre-Cambrian, with an intervening period of erosion. The maximum thickness, 151 feet, was found in Priest Canyon, with an average thickness of about 100 feet. No shales were found in sections west of the Front Range. In the Arkansas River section below Salida it was found to be entirely a quartzitic

FIG. 4.—Typical exposure of Harding showing sand and shale slope. Thin wedge of Manitou is shown beneath Harding. This is southernmost exposure of Manitou. Fremont limestone cliff is shown above Harding slope. Priest Canyon.

sandstone containing the fish remains, with a thickness of 50 feet. Sandstone containing the typical fish remains was also found in a section measured on Cement Creek in T. 14 S., R. 84 W., Gunnison County, Colorado, lying below the Yule limestone, and probably resting on the Sawatch.[1]

Fish remains are abundant in some sandstones in all of the sections measured, and many badly weathered invertebrate fossils occur in the shales. Collections were made from each section, but identifications have not been completed. It is placed in the Black River division of the Upper Ordovician by the United States Geological Survey,[2]

[1] *U. S. Geol. Survey, Anthracite-Crested Butte Folio 9*, p. 6.

[2] *Colorado Springs Folio 203*, p. 6.

which makes it the equivalent of at least the upper part of the Simpson of Oklahoma.

The occurrence of oil in beds of Black River age in widely separated parts of the United States makes the determination of the limits of deposition of the Harding of economic importance. Its correlation with the Simpson of Oklahoma and Kansas makes it probable that they were deposited in the same sea, and that they will be found to be continuous through eastern Colorado and western Kansas, except where locally removed by erosion. The Continental Oil Company's Pipe Springs well in Sec. 27, T. 27 S., R. 49 W., Bent County, Colorado, passed through a series of fine sands and green shales representing the Harding, from 5,895 to 5,995 feet. This zone was overlain by limestone of probable Fremont age (Viola), and rested on limestone which is probably Manitou. The zone is missing, either from erosion or non-deposition, on the top of the Las Animas arch, a land mass of Pennsylvanian or earlier age in southeastern Colorado.

Fremont limestone.—The type locality of the Fremont is at Harding's Quarry near Cañon City, and the name is derived from Fremont County. It was named and described by Walcott,[1] and the type section is here quoted as Table IV.

TABLE IV

FREMONT LIMESTONE

Base		*Feet*
2	Red and purple fine-grained argillaceo-arenaceous shale	2–4
	Fossils. Rolled and worn fragments of fish plates occur in the lower portion.	
3	Gray siliceous magnesian limestone, somewhat ferruginous in the lower portion. Locally, this decomposes to a reddish, friable rock and soil; the entire mass above 25 feet from the base weathers into rough, irregular cliffs with numerous shallow caverns and holes of various sizes and forms	170
	Fossils. The lower layers are, in places, made up largely of the casts of corals and mollusks, but well preserved specimens are rare. Corals were observed in abundance in the lower 10 feet of the limestone on the northern side of the road leading from Cañon City to Parkdale, a little east of where it enters on the pre-Paleozoic rocks. In the lower 3 feet at the Harding Quarry and immediately toward the north, there have been collected the species mentioned in the list, pages 159, 160.	
4	*a*. The upper portion of *3* passes into a hard, compact, light-colored limestone	45
	Fossils. *Zaphrentis* and fragmentary casts of gastropods.	
	b. Dark reddish brown sandstone	10
	c. Compact, hard light gray limestone breaking into angular fragments and with a band of purple and gray calcareo-arenaceous shale at the base	45
	Fossils. A large and varied fauna occurs of a Trenton type. (See list, pages 161, 162)	
5	Impure variegated banded limestone with interbedded sandstones and argillaceous beds	15–30
	Fossils. *Spirifer* sp., *Athyris subtilita.*	

[1] C. D. Walcott, *Bull. Geol. Soc. Amer.*, Vol. 3 (1892).

Observations on the Fremont Limestone Series.—The line of demarkation between the upper beds of the Silurian (Ordovician) and the superjacent limestone in which Carboniferous fossils occur is not strongly defined, although it represents a long period of non-deposition and a great time break. The Carboniferous limestones are sometimes brecciated and lithologically unlike those below. No traces of the Silurian and Devonian groups have been obtained.

The Fremont rests unconformably on the Harding sandstone, although this is not apparent in some exposures. In the Beulah section it rests on an irregular surface of a Harding shale, as is well shown in Figure 5. Close examination of the contact along the road following Oil Creek to Garden Park also reveals irregularities. A section measured in Sec. 26, T. 15 S., R. 76 W., Park County, shows the Fremont seemingly resting at a lower angle than the underlying Harding. In no section is there evidence of a gradational change, and it is therefore

Fig. 5.—Irregular contact between Fremont limestone and Harding shale just west of Beulah.

believed that a short period of erosion intervened between the Harding and the Fremont throughout this region. This is also suggested in Walcott's type section by the lowermost bed, 2, of the Fremont, which contains weathered material from the Harding. A distinct erosional unconformity was found both in the section at Beulah and on Oil Creek.

The maximum thickness of 270 feet is found in Priest Canyon northwest of Cañon City, and decreases rapidly toward the east and south because of erosion of the upper part. A few remnants were found in the section west of Beulah; these remnants either were not found or were included with the Mississippian by Gilbert in his work on the Pueblo Quadrangle. Just one thin block was recognized in the

Phantom Canyon section and none farther east or north. It is widespread in central Colorado. The rapid variation in thickness along the Front Range is probably due to pre-Mississippian warping and subsequent erosion, as no evidence of a shoreward phase or an overlapping of the succeeding formations on a rough topography has been found.

It is a gray to blue-gray, in places pinkish, crystalline magnesian limestone, which weathers to a characteristically rough surface. Fossils are fairly abundant in some shaly beds and throughout the limestone. The distinctive chain coral, *Halysites catenulatus*, and *Receptaculites owenii* are rather common. The fauna from the lower part was identified by Walcott as Trenton and believed by Kirk[1] to correlate with the Kimmswick lime of Missouri. The upper part is generally believed to be as young as Richmond. This indicates its correlation with the Viola and possibly Sylvan of the Arbuckle Mountains of Oklahoma, and the Kimmswick and Fernvale of the Ozarks, but no evidence was found to place an unconformity within the Fremont, such as is known to occur within the Viola and between the Kimmswick and Fernvale. The Montoyo limestone of the Franklin Mountains of West Texas, the Big Horn dolomite of Wyoming, and Fishhaven of Idaho, also, are closely equivalent.

SILURIAN

No beds of Silurian age corresponding with the Fusselman limestone of the Franklin Mountains or the lower part of the Hunton of Oklahoma are known to occur along the Front Range.

DEVONIAN

Williams Canyon limestone.—About 30 feet of thin-bedded limestones and calcareous shales occur in the section along the Front Range unconformably below the Mississippian (Madison limestone) and unconformably above the Ordovician beds. This series is typically exposed near the Cave of the Winds in Williams Canyon at Manitou, and tentatively the name, Williams Canyon limestone, is given to the series. Excellent exposures are found in Manitou Park, at Perry Park, in the Cañon City embayment, and at Beulah on the east slope of the Wet Mountains.

The name Millsap limestone was applied by Cross[2] to 30 feet of thin-bedded dolomitic limestone with a few thin sandstone layers exposed between Oil and Millsap creeks northeast of Cañon City. Chert

[1] Personal communication—Reeside to Brainerd, opinion of Edwin Kirk.

[2] Whitman Cross, *U. S. Geol. Survey Geol. Atlas, Pikes Peak Folio* 7, p. 2.

nodules in the upper part carry fossils identified as Carboniferous. This series is believed by the writers to be equivalent to the thin-bedded section in Williams Canyon and the chert nodules derived from erosion of the overlying Madison and deposited in the basal Pennsylvanian, which in this area overlies the thin-bedded limestones.

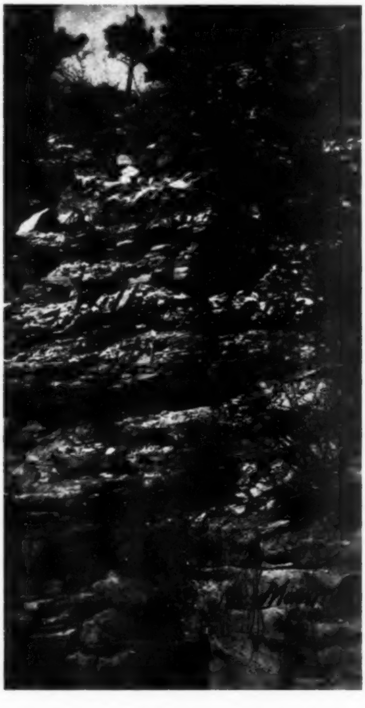

FIG. 6.—Typical exposure of Williams Canyon limestone resting on Manitou limestone. Thin-bedded limestones and calcareous shales are well shown and very characteristic. Photograph in Manitou Park.

The name Millsap was later used for the thin-bedded limestones together with the overlying thick massive Madison limestone west of Beulah.[1] The name Millsap might now be applied to the thin-bedded section at Beulah were it not for the fact that this name is pre-occupied in the literature by a Pennsylvanian formation in Texas. On account of this fact, the writers use the name, Williams Canyon lime-

[1] C. G. Gilbert, *U. S. Geol. Survey Geol. Atlas, Pueblo Folio 36* (1896).

stone, because of the typical exposure in Williams Canyon at Manitou.

The Williams Canyon limestone consists of thin, white to gray limestone, 2–6 inches in thickness, with partings of gray calcareous shale, and occasional thin sandstones. It occurs in all sections measured with the exception of those between Manitou Springs and the Oil Creek section. Its maximum thickness of 65 feet was found at Missouri Gulch, in Manitou Park. It lies unconformably on the Manitou, Harding, or Fremont, and the Madison or later beds rest unconformably above.

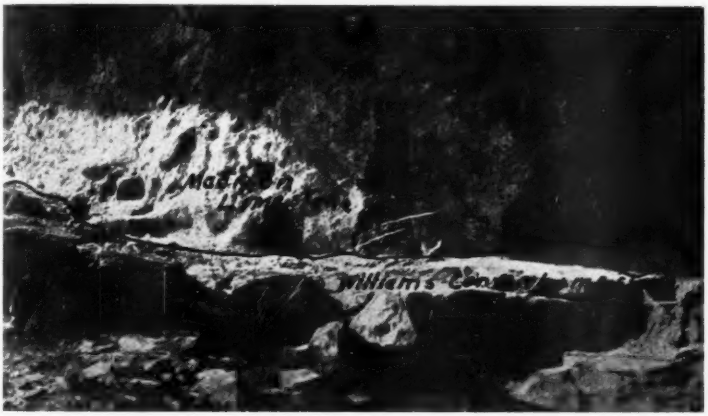

FIG. 7.—Photograph taken just west of Beulah. Excellent illustration of irregular contact between Madison limestone above and Williams Canyon limestone below.

A description of the type section has already been given in the Williams Canyon stratigraphic section. The section given in Table V was taken at Beulah on the east slope of the Wet Mountains. It shows the relationship of this series at its southern exposure.

Careful search has revealed no fossils, and samples of the Williams Canyon limestone and shale breaks were reported by Brant[1] to contain no micro-fossils. A possible correlation is with the lower or Devonian part of the Ouray limestone of central Colorado.[2] The Devo-

[1] Ralph A. Brant, personal communication.

[2] E. M. Kindle, "The Devonian Fauna of the Ouray Limestone," *U. S. Geol. Survey Bull. 391* (1909).

S. F. Emmons, J. D. Irving, and G. F. Loughlin, "Geology and Ore Deposits of the Leadville Mining District, Colorado," *U. S. Geol. Survey Prof. Paper 148* (1927), p. 36.

nian Elbert formation of southwestern Colorado[1] has not been definitely identified east of Glenwood Springs, where it is quite different lithologically from the Williams Canyon limestone, but their correlation is a possibility. The sandstones in the Williams Canyon

TABLE V

BEULAH SECTION, PUEBLO COUNTY, COLORADO

Measured by hand level on north side of creek 1½ miles west of Beulah, in Sec. 5, T. 23 S., R. 68 W.

			Feet
PENNSYLVANIAN			
	Fountain Formation		
14	Conglomeratic sandstone, arkosic		
13	Sandstone, very fine grained, similar to Harding		6
	Unconformity		
MISSISSIPPIAN			
	Madison		
12	Limestone, cherty, gray	35	35
11	Limestone, gray, massive at base, thin-bedded at top. Cross-bedded at top. Solution cavities filled with material from Fountain	30	65
10	Limestone, massive, light to dark gray, very fine grained. Many cavities filled with brecciated limestone. Forms slope	80	145
9	Limestone, massive, light to dark gray, very fine grained. Much brecciated material filling cavities. Several thin chert beds near base, fossiliferous bed with several spirifers and brachiopods just above the chert. Forms cliff	65	210
DEVONIAN			
	Unconformity (Irregular surface)		
	Williams Canyon Limestone		
8	Limestone, 2–6 inch beds, light gray to pink, fine grained, thin partings of gray calcareous shale and sandstone lenses	20	230
	Unconformity		
ORDOVICIAN			
	Fremont Limestone		
7	Limestone, gray, coarsely crystalline. Many crinoid stems, compound corals. Top very irregular	0–20	245
	Unconformity		
	Harding Sandstone		
6	Sandstone, very fine grained. Missing in places from unconformity	0–2	247
5	Shale, poorly exposed, brown, weathering yellow	12	259
4	Sandstone, very fine grained, thin bedded	13	272
3	Shale, brown, fossiliferous	26	298
2	Sandstone, very fine grained, well bedded	22	320
	Thickness of Harding	75	
	Unconformity		
PRE-CAMBRIAN			
1	Metamorphic rocks		

limestone in Manitou Park and at Manitou Springs and the general lithology suggest a closer equivalence with the Parting quartzite of central Colorado. The exact Devonian age of the Parting quartzite is

[1] Whitman Cross, *U. S. Geol. Survey Geol. Atlas, Engineer Mountain Folio 171* (1910), p. 5.

E. M. Kindle, *op. cit.*

unknown, but it may be a sandstone phase of the Elbert formation. The writers are inclined to believe that the Williams Canyon limestone is the equivalent of the Parting and of Devonian age.

MISSISSIPPIAN

Madison limestone.—Many of the horizons from which Mississippian fossils have been reported from the Front Range[1] are believed to be basal Pennsylvanian, in which the fossils occur in chert nodules derived from erosion of the Mississippian. However, the massive limestones below the Pennsylvanian Fountain formation northwest of Beulah, at Manitou Springs, and in Manitou Park and some distance northward, have been recognized as true Mississippian and essentially equivalent to the Madison of Wyoming and Montana.

FIG. 8.—Photograph taken just west of Beulah, illustrating massive, cliff-forming character of Madison limestone.

Although this is largely a lithologic correlation, a number of Mississippian fossils have been found at Beulah and in Manitou Park, and a crinoid, *Actinocrinus marcoui Collignon* of Kinderhook age, was found by Marcou in the limestone in Williams Canyon.[2]

It is a thick, massive, white-to-gray limestone, with practically no bedding. It forms steep escarpments, and is generally recognizable from a distance by its appearance. The upper part is commonly brecciated from pre-Pennsylvanian weathering. In the cliffs northwest of Beulah, there are many examples of "fossil caves" in which large solution cavities have been filled with limestone boulders, red sandstone,

[1] G. H. Girty, *op. cit.*, pp. 224–26.

[2] M. Collignon, *Bull. Soc. Geol. France*, 4th ser., Vol. 24 (1924), pp. 13–14.

and conglomerates similar to those found in the Fountain formation above. Its thickness ranges from almost nothing to 200 feet, varying principally as a result of erosion of the upper part.

Scarcity of fossils prevents determination of the age of the Madison in Colorado more definitely than lower Mississippian. It is the equivalent of the Leadville of the West Slope and the upper part of the Ouray of southwestern Colorado and is essentially equivalent to the Madison of Wyoming, Idaho, and Montana, the Pahasapa of the Black Hills, and the Boone of Missouri.

It is believed that the Madison was deposited over the entire area of what is now the Front Range, but was removed from the greater part by pre-Pennsylvanian erosion, as evidenced by the occurrence of Mississippian fossils in chert nodules in the basal Pennsylvanian from many localities as far north as southern Wyoming.[1]

COMPARISON WITH PREVIOUS CORRELATIONS

Pueblo Quadrangle.—The only change in the present correlation from that given in the Pueblo Folio by G. K. Gilbert, is the division of the Mississippian, therein called the Millsap, into the Madison and Williams Canyon limestone, and the identification of a thin wedge of limestone between the Harding and Beulah as the Fremont.

Pikes Peak Quadrangle.—The Mississippian fossils found near the top of the thin-bedded limestones above the Ordovician are considered by the authors as coming from re-worked Madison fragments in the basal Pennsylvanian, and these thin limestones, to which the name, Williams Canyon limestone, has been given, are considered of Devonian age. No Madison was found, although isolated remnants may occur.

Colorado Springs Quadrangle.—The changes in the classification of the section in the Colorado Springs Quadrangle may be seen by referring to the Williams Canyon section. Beds *3–14* were included in the Manitou limestone by Finlay.

TABLE VI

GOVE CANYON SECTION, DOUGLAS COUNTY, COLORADO

Measured at mouth of canyon, on west side of creek, NE. ¼ Sec. 2, T. 10 S., R. 68 W.

		Feet
PENNSYLVANIAN		
7	Shale, red, succeeded by arkosic sandstones of Fountain formation. Included in the Millsap in the Castle Rock Folio	
6	Brecciated limestone, containing chert boulders with many Mississippian fossils. Some may be in place, but probably all a conglomerate of boulders from weathered Madison cemented by lime	1–8

[1] Willis T. Lee, "Correlations of Geologic Formations between East-Central Colorado, Central Wyoming and Southern Montana," *U. S. Geol. Survey Prof. Paper 149* (1927), p. 5.

	Unconformity	
DEVONIAN		
	Williams Canyon Limestone	
5	Limestone, thin-bedded, gray, with beds and lenses of coarse sand; sandy limestone; and thin breaks of gray shale	25
4	Sandstone, coarse grained, massive, base very irregular	½–2½
	Local Unconformity	
3	Limestone, sandy at base, a few thin breaks of gray shale, light gray, poorly bedded	21
	Thickness of thin-bedded ... 48	
	Unconformity	
CAMBRIAN		
	Sawatch Sandstone	
2	Sandstone, white except for a few feet of red at top and some red streaks, medium grained, with many coarse grains and small pebbles. Rests on a nearly plane surface of granite	90
	Unconformity	
PRE-CAMBRIAN		
1	Pikes Peak granite	

On comparing this section with the one given by Richardson on page 4 of the Castle Rock Folio, it is seen that the red shale has been placed in the Pennsylvanian instead of the Mississippian, and that only a possible thin remnant of Madison (bed *6*) was found. The thin-bedded limestones below belong to the Williams Canyon formation, which rests on the Sawatch sandstone.

TABLE VII

FISH HATCHERY SECTION, MANITOU PARK, DOUGLAS COUNTY, COLORADO

Measured in tributary entering Trout Creek from east at Fish Hatchery, about Sec. 22, T. 10 S., R. 69 W.

			Feet
MISSISSIPPIAN			
	Madison Limestone		
7	Limestone, light gray, massive, brecciated, slightly cherty	50	50
DEVONIAN			
	Williams Canyon Limestone		
6	Limestone and calcareous shale, thin-bedded, light gray. Several sandy limestones and coarse-grained sandstones at top	48	98
5	Conglomeratic sandstone	2	100
	Unconformity		
ORDOVICIAN			
	Manitou Limestone		
4	Limestone, thin-bedded, brown and gray, thin breaks of calcareous gray shale. Fossiliferous, with many trilobites and brachiopods. Sandy at base	58	158
	Unconformity		
CAMBRIAN			
	Sawatch Sandstone		
3	Sandstone, blue-gray, fine grained	5	163
2	Sandstone, massive, but with good bedding planes, brown, weathering yellowish brown, coarse grained. Some arkosic conglomerate in lower part, with sub-angular quartz and feldspar pebbles. Rests on irregular surface	53	216
	Unconformity		
PRE-CAMBRIAN			
1	Granite, very large crystals		
	This section is very well exposed		

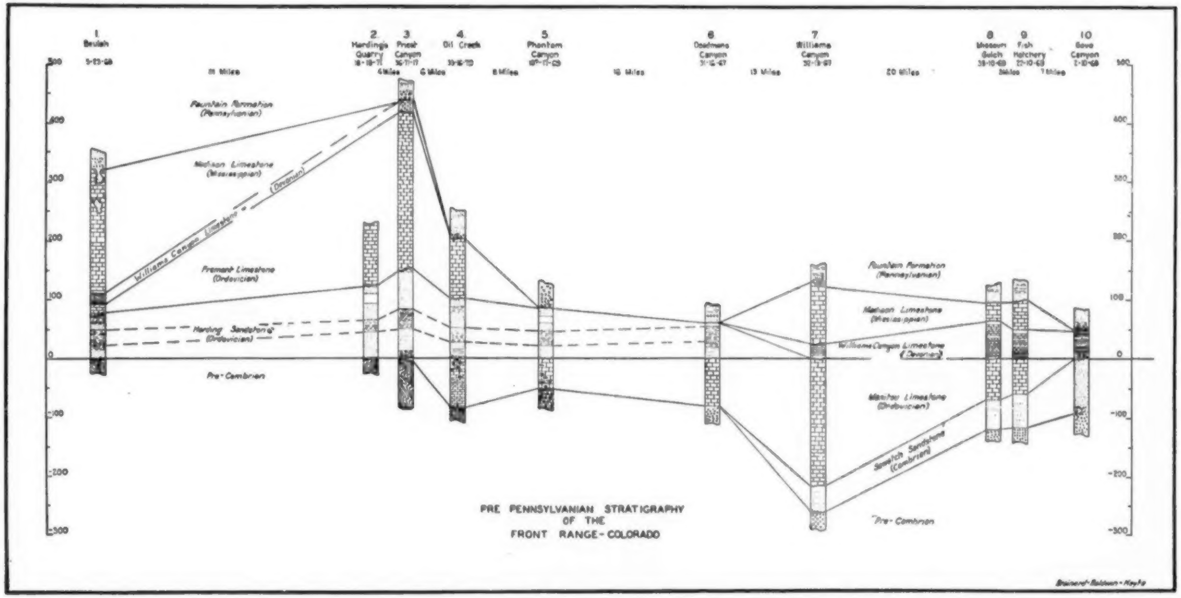

FIG. 9.—Stratigraphic cross section to illustrate changes in pre-Pennsylvanian formations along Front Range in Colorado from southern to northern exposure. Sections numbered according to numbered localities on index map.

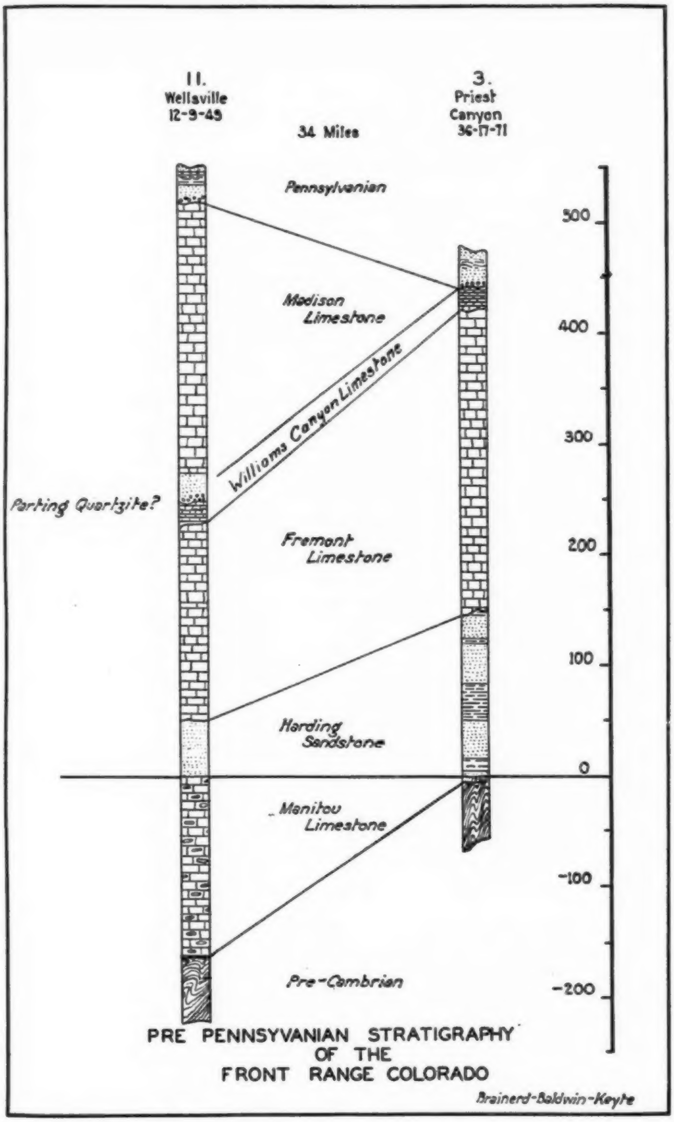

FIG. 10.—Stratigraphic cross section to illustrate changes in pre-Pennsylvanian formations from Front Range westward to Wellsville. Sections numbered according to numbered localities on index map.

Since no detailed sections other than the ones measured by A. C. Peale in 1873 have been found, it is impossible to determine how the limestones above the Sawatch have been previously correlated, but it is believed that they were all included in the Manitou of the Pikes Peak Folio by Whitman Cross.

Figure 9 and Figure 10 show the distribution of the various formations along the Front Range, and the unconformities separating them.

These cross sections summarize graphically the main points which the writers have brought out in the text. The presence of fairly complete Paleozoic sections from Colorado Springs to Cañon City and westward through the Salida area to the West Slope, indicates the existence here of a fairly continuous trough throughout Paleozoic time. The unconformities which exist between the various formations show an oscillating condition throughout this same time, with the removal of parts of each formation from at least portions of the area of the present Front Range, and probably, in some instances, throughout wide areas. These movements culminated in the extremely widespread uplift at the end of Mississippian time, which removed the Madison and perhaps later Mississippian strata from much of the area occupied now by the Rocky Mountain ranges. That the Madison covered much, if not all, of the area now occupied by the Rocky Mountains is indicated by the present distribution of the outcrops, the lithologic character of the formation, and the presence of fossiliferous chert fragments derived from the Madison and found fairly widespread in the base of the overlapping Pennsylvanian.

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MONTANA GROUP IN EASTERN COLORADO[1]

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ABSTRACT

The Upper Cretaceous Montana group of eastern Colorado contains six distinctive zones and several beds which are recognizable at widely separated localities and are, in some cases, useful in determining both the regional and local structure of the gently folded plains region. New data on the lithologic and paleontological character of the Fox Hills sandstone, as re-defined, are included.

INTRODUCTION

Prior to about 1929 most of the geological investigations in eastern Colorado were carried out sporadically in scattered localities, with the result that persistent key beds were generally thought to be absent from the Upper Cretaceous Montana group in that area. Several years of detailed work by the writer in all areas where the Montana group crops out show, however, that it contains several distinctive zones and beds which are recognizable at widely separated localities and are of great assistance in determining the regional and detailed structure of the gently folded plains region.

ACKNOWLEDGMENTS

The writer is indebted to the Continental Oil Company and to Glenn C. Clark for permission to publish this paper; also to A. E. Brainerd, C. E. Dobbin, C. H. Rankin, and H. F. Davies for assistance in measuring some of the stratigraphic sections and for constructive criticism of the manuscript.

GENERAL SECTION

The Montana group in eastern Colorado consists of two formations—the Pierre shale and the Fox Hills sandstone—whose combined thickness in the plains region varies from about 4,300 feet in the Horse Creek area, in Elbert and Lincoln counties, to over 6,000 feet west of Greasewood Flats, in Weld County. However, at their out-

[1] Presented before the Association at the Oklahoma City meeting, March 25, 1932. Manuscript received, January 25, 1933. Published with the permission of the chief geologist, Continental Oil Company.

[2] Geologist, Continental Oil Company.

crops near the foothills along the western limb of the Denver-Greeley syncline, the combined thickness of these formations is as much as 7,500 feet, decreasing to less than 3,500 feet along the outcrop in the southern part of the state. The two formations grade into each other lithologically and paleontologically. The Pierre shale and the beds formerly assigned to the lower part of the overlying Fox Hills sandstone are divisible into five zones, some of which grade into one another, but nevertheless are clearly distinguishable.

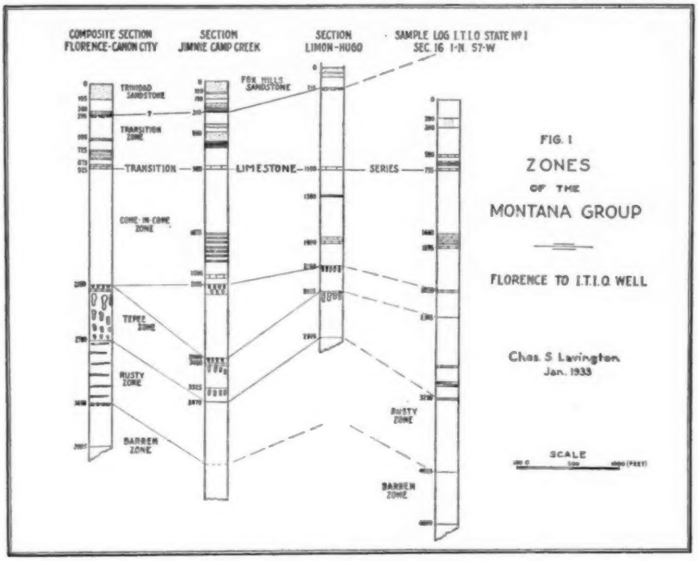

FIG. 1.—Zones of Montana group.

ZONES OF MONTANA GROUP

Barren zone.—The Barren zone, as identified by Gilbert,[1] is the basal zone of the Pierre shale and one of the most distinctive and easily recognizable divisions of that formation. It is usually called the "black shale zone" by drillers. It consists of dark brown to black, tough, fissile clay shale, with large, oval, gray calcareous septarian concretions, many bentonite beds, and many thin layers of yellow, powdery limonite. Southeast of Florence it contains, in addition, some peculiar thin beds that resemble partially clinkered stove ashes. The septarian concretions weather to a light gray and are 3 feet or more in

[1] G. K. Gilbert, "Pueblo Folio," *U. S. Geol. Survey Geologic Atlas* 36, p. 3.

diameter. In the Walsenburg district this zone contains a 20-foot sandstone member which H. W. C. Prommel in an unpublished report has called the Apache sandstone. In the Pueblo district the zone contains in the lower part many sandstone beds as much as ½-inch thick. Unweathered outcrops of the zone are nearly black. Although the zone is sparingly fossiliferous, a few *Inocerami* and vertebrae have been found, and north of Florence in the southwest corner of Sec. 21, T. 18 S., R. 69 W., a boring mollusk, probably of the genus *Martesia*, was collected from the remains of woody material in the shale. The zone is 475 feet thick east of Florence, 490 feet thick north of Cañon City, about 420 feet thick at Leydon Gulch on the Denver and Salt Lake Railway, 6 miles north of Golden, and about 575 feet thick in northeastern Colorado. No complete section of the zone has been measured in the plains proper. Characteristic outcrops of the zone occur near Haswell, Kiowa County, Colorado; northeast of McAllaster, Logan County, Kansas; northeast of Chadron in northwestern Nebraska; and in southwestern South Dakota. It can also be identified from well cuttings in northeastern Colorado.

Oil can be distilled from the shale in the Barren zone at Florence, and it is probable that the zone is the source rock of the Florence-Cañon City oil. Although the zone has yielded showings of oil in many wells, it has never yielded oil in commercial quantity, probably because of its failure to fracture easily and the consequent lack of reservoir space. In wells at several localities in eastern Colorado, good showings of gas have been found in this zone, and a 500-foot well in the southeast corner of Lincoln County has supplied gas to a farm from this zone since 1917.

Rusty zone.—The Rusty zone, also named by Gilbert,[1] directly overlies the Barren zone and is differentiated from it by the occurrence of numerous ironstone beds, which individually attain a thickness of several inches and cause by oxidation the characteristic rust-colored outcrops. Where the lower part of the zone crops out southeast of Florence, the interval between the ironstone beds averages about 3 feet. There, too, each ironstone bed is represented at the outcrop by innumerable weathered fragments that litter the surface of the ground. The shales of this zone are dark gray to black and contain, besides the numerous ironstone beds, many bentonite beds, and towards the top several brown concretionary limestone beds. The entire zone is rarely exposed at any one locality in the plains region. Along the west side of Baculite Mesa, northeast of Pueblo, the upper part of the zone is well exposed and small conical buttes from the overlying

[1] *Op. cit.*

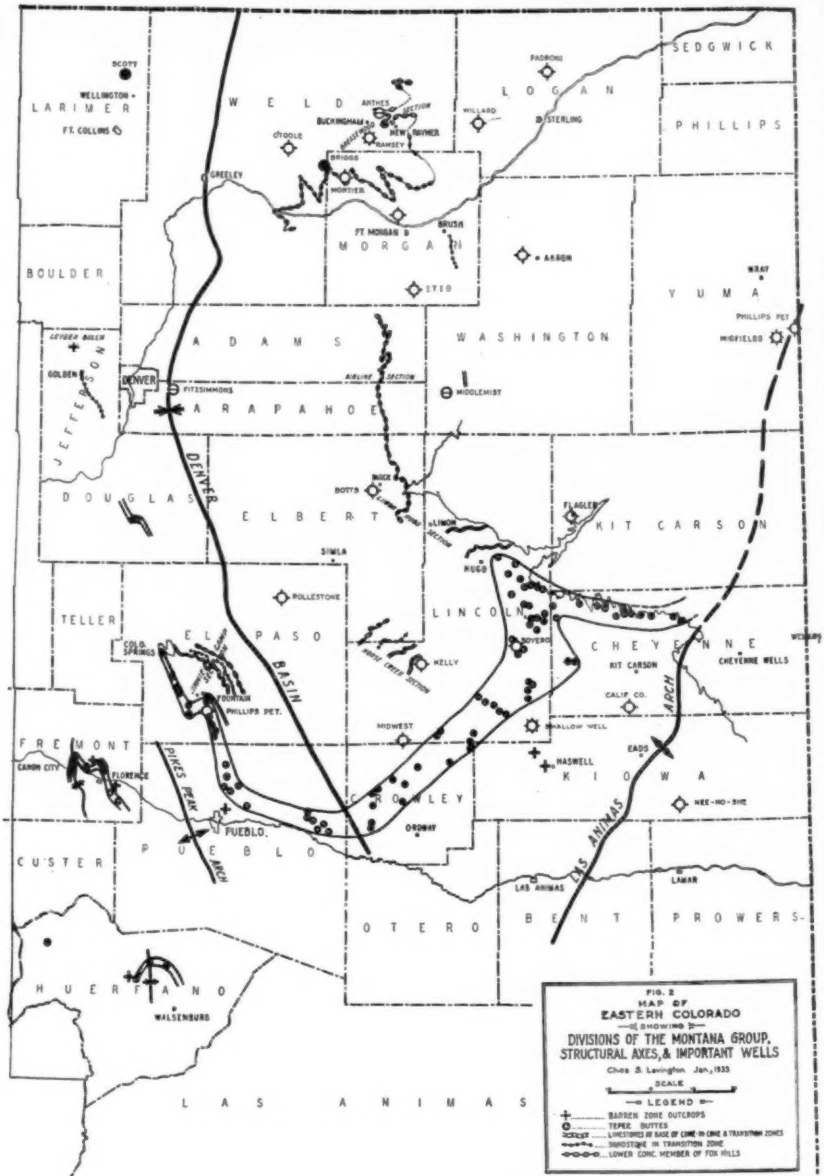

FIG. 2.—Map of eastern Colorado showing divisions of Montana group, structural axes, and important wells.

Tepee zone range well down into it. About 3 miles east of Pueblo and north of the Ordway road, the basal part of the Rusty zone, together with the black shale of the Barren zone, form a low escarpment with a northwest strike. The zone averages 670 feet in thickness in the Florence district and about 800 feet in northeastern Colorado.

Tepee zone.—The Tepee zone contains the most conspicuous concretion masses in the Pierre shale and has been described by several earlier writers. According to Darton,[1]

FIG. 3.—Typical outcrops of Tepee zone southeast of Fountain, Colorado.

The masses consist of "coarse gray fossiliferous limestone, irregular or rudely cylindrical in form and standing vertical in the shale mass. Ordinarily they are from 5 to 30 feet in horizontal diameter and their vertical extent is greater. As the wash of the rain carries away the shale, these cores—being more resistant—are left projecting from the surface." In a measure they protect the shale from erosion and so give rise to conical hills with shale slopes and a mass of limestone at the top. On account of their shape they have been called Tepee buttes. The characteristic fossil in the limestone is a small shell about an inch wide known as *Lucina occidentalis.*

Farther on Darton writes

One of these is the upper horizon of concretions with *Lucina occidentalis,* giving rise to "Tepee buttes," which appears to extend from the Arkansas Valley through Colorado to and all around the Black Hills.[2]

Lucina occidentalis is more than merely the characteristic fossil of the Tepee zone, for in many places the cores of the buttes are composed almost entirely of these shells. The cores were probably built up as reefs by successive colonies of this species, and their distribution controlled by the type of sea bottom and the available amount of

[1] N. H. Darton, "Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains," *U. S. Geol. Survey Prof. Paper 32* (1905), p. 108.

[2] *Op. cit.*, p. 169.

calcium salts contained in the water.[1] The limestone forming the cores of the tepee buttes varies from light to dark gray or brown in color and is commonly very porous. It has been suggested[2] that the tepee buttes may represent the offshore deposition of the remaining colloidal silica and calcium carbonate left in solution at the outer margin of such sandy deposits as the Hygiene group in the Denver Basin and the Eagle (?) sandstone of southeastern Montana. The abundance of *Lucina* shells is explained by their desire for a mud as opposed to a sandy sea bottom. The Tepee zone contains the same fauna as the Hygiene group and passes into the lower part of that group as the trough of the Denver Basin is approached.[3] West of Berthoud incipient tepee buttes occur in the Hygiene group, but contain few, if any, *Lucina occidentalis*. South of Wray, *Lucina occidentalis* occurs abundantly at a horizon 100 feet or more above the surface at the Philips' Andrews well No. 1 in approximately the tepee buttes horizon and yet does not show the peculiar tepee butte habit. North of Weskans, Kansas, which is considerably farther away from the edge of the Hygiene group, typical tepee buttes occur, however.

The Tepee zone in the plains area is composed of 500 to about 1,200 feet of gray clay shales with many bentonite beds—the largest of which reach nearly a foot in thickness—limestone beds, and the peculiar limestone cores already described. The main series of Tepee buttes occupies the lower 500 feet of the zone, although limy concretions anywhere in the zone may exhibit similar characteristics to a less extent. This series thins to 200 feet or less at Cañon City and in other areas close to the mountains. In the Florence area a persistent horizon of well-developed limestone concretion beds occurs near the top of the main series and probably represents a similar series in the plains area, particularly east and southeast of Fountain. South and east of Hugo some concretions 300 to 700 feet above the main series form small tepee buttes, and contain, besides *Lucina occidentalis*, many small gastropods. A similar series, with the exception that no gastropods were found, occurs in the Fountain area about 800 feet above the main series. The top of these smaller tepee buttes is the top of the zone, although some well developed cone-in-cone beds occur between these and the main series and some incipient tepee buttes occur in the overlying zone.

The Tepee zone in general contains many fossils of several dif-

[1] W. H. Twenhofel *et al.*, *Treatise on Sedimentation* (1926), p. 231.

[2] H. F. Davies, personal communication.

[3] Junius Henderson, personal communication.

ferent genera. A collection made east of Florence was identified by Professor Junius Henderson of the University of Colorado as follows.

Lucina occidentalis	*Inoceramus vanuxemi*
Scaphites nicoletti	*Inoceramus barabini*
Scaphites nodosus	*Baculites compressus*
Heteroceras sp.	Gastropod (unidentified)

Besides the occurrences mentioned, tepee buttes are present in the Walsenburg, Huerfano Park, Colorado Springs, and Perry Park areas, and similar concretionary cores can be recognized in some of the deep wells of northeastern Colorado.

The Baculite zone said by Gilbert to occur beneath the Tepee zone in the Pueblo district is not believed to be a persistent zone over widespread areas.

Cone-in-cone zone.—Although cone-in-cone beds occur throughout the Pierre, they seem to be more prevalent in, and rather characteristic of, the gray clay shale zone lying between the main Tepee butte series and the Transition zone above. Besides the cone-in-cone beds, these shales contain ironstones similar to those of the Rusty zone (but not as numerous), limy concretion beds, and in places, thin sandstones, and a few bentonite beds. The bentonites of this zone are more abundant in and near a series of blue to gray concretionary limestone beds in the lower part. This series has a thickness of 65 feet in the Hugo area and forms three distinct benches in the topography. It is thought that it can be recognized in three different stratigraphic sections measured, and in the logs of three wells. The zone is 1,050 feet thick in the Limon-Hugo area, 1,200 feet thick in the Jimmie Camp area, 1,255 feet thick in the Florence area, and thickens northward from Limon to 1,300 feet or more. The best exposure of the limestone series of this zone is northeast of Hugo in Secs. 14, 15, and 22, T. 10 S., R. 54 W.

Transition zone.—The Transition zone includes the beds which lie between the mappable group of sandstones and sandy concretion beds of the Fox Hills sandstone, as now defined, and the lower beds which contain typical Pierre fossils. It is composed of gray, blue, and buff shales and sandy shales, scattered buff calcareous concretions, sandstones and several thin gray-to-buff concretionary limestone beds. An especially well-developed and persistent group of the latter, which range in color from buff-to-gray and purplish, is at the base of the zone. These limestones are fossiliferous and contain *Inoceramus fibrosa*, *Baculites*, and *Ammonites*. This group can be recognized at several localities and in at least two well logs. It is probably represented in the Florence area by a similar group occurring immediately below the

thin sandstone beds which form a low escarpment along the eastern border of the oil-producing area. These sandstones are fossiliferous, as are the limestones, and contain an abundance of *Mactra holmesi.* Near the middle of the zone is a 4-inch bed of gray shaly limestone which occurs in shales of a peculiar bluish color in the railroad cuts east of Limon. This bed, which is ordinarily exposed in steep shale banks along some of the creeks, can be recognized at several localities from Limon northward. South of Brush, and on Horse Creek and Jimmie Camp Creek, sandstones come well down into this zone. On Horse Creek, south of Simla, in Sec. 34, T. 13 S., R. 58 W., there is an outcrop of coarse brown sandstone with two thin limestone beds a few feet below. Both the sandstone and the limestones are very fossiliferous and John B. Reeside, Jr., identified *Sphenodiscus, Baculites, Callista, Discoscaphites, Mactra, Lucina, Nucula,* and *Protocardia* from this horizon when this locality was visited by the Rocky Mountain Association of Petroleum Geologists in May, 1932. This sandstone, the outcrop of which stands out prominently on account of a thick ironstone cap, occurs at about the same stratigraphic position as the one that crops out south of Franceville near the center of Sec. 7, T. 15 S., R. 64 W., and which has similar fossiliferous thin limestones just below it. These beds also seem to correlate with the sandstone which occurs several hundred feet below the Laramie formation along the Front Range from Leyden Gulch southward, and which is encountered in deep wells in the vicinity of Denver. There is a good exposure of this sandstone west of the clay pits adjacent to Guggenheim Hall of the Colorado School of Mines at Golden. There it is very fossiliferous and yields an abundance of *Mactra.* This sandstone bed is not continuous across the Denver Basin, however, as it was not encountered in either the Botts or Calhan wells, or in outcrops of this zone west and northwest of Limon. The sandstone mentioned south of Brush, which comes in at about the same stratigraphic position, contains many *Inoceramus fibrosa.* At its outcrop on the northeast side of the Denver Basin this bed lies about 600 feet below the concretionary zone of the basal Fox Hills that is so well developed in the Greasewood area, while on the south side it is considerably less. The thickness of the Transition zone totals about 650 to 875 feet in the Jimmie Camp, Horse Creek, and Limon-Hugo areas, but increases perceptibly northward toward the Greasewood area. In the Florence-Canon City district, where the Fox Hills is restricted to the Trinidad sandstone, it measures 720 to 800 feet and the shales become more and more sandy as the Trinidad sandstone is approached. The fol-

lowing fossils were collected from this zone in the vicinity of Florence and were identified by Junius Henderson.

Scaphites nodosus	*Anchura* sp.
Baculites compressus	Pelecypod (unidentified)
Inoceramus sagensis	*Mactra holmesi*
Pecten sp.	*Mactra* sp.

The best exposures of the basal limestone group, which averages about 50 feet in thickness, are southeast of Limon in Sec. 14, T. 9 S., R. 55 W., on the Farmers Highway one mile east of Horse Creek bridge in Sec. 12, T. 14 S., R. 58 W., on the north and east sides of the Fountain "Nose," and on the east edge of Colorado Springs on Boulder Street north of the Printers Home.

Fox Hills sandstone.—At a field conference of the Rocky Mountain Association of Petroleum Geologists in May, 1932, at which John B. Reeside, Jr., officially represented the United States Geological Survey, it was decided that the Fox Hills sandstone of eastern Colorado be limited to the mappable group of buff sandstones and sandy concretion beds at the top of the Fox Hills, as previously defined. The base is now defined as that horizon below which the strata are predominantly gray marine shale and above which the section changes rapidly to buff or brown marine sandstone containing numerous large, gray-to-brown, hard, sandy concretions. The top is now considered as the horizon above which occur predominantly fresh and brackish-water sandstone and shale, coal, and lignitic shale.[1] The Fox Hills is composed of buff or brown sandstone, buff-to-gray sandy shale, and brown-to-gray sandy concretion beds deposited in a retreating Cretaceous sea. It is essentially marine, although there were intervals in which brackish-water sediments were deposited during a temporary recession of the sea. It is very fossiliferous in places and in the Greasewood area some of the fossil beds make excellent markers. The most prominent bed of the formation is a fine buff sandstone containing large, extremely hard, dense, irregular, brown sandy concretions. These concretions vary up to 10 feet or more in diameter and many are very fossiliferous. Although several similar beds come into the section toward the east and northeast, the one which crops out near the wells in the Greasewood oil field, and which occurs 80–100 feet above the base of the formation, is the most prominent and is the datum bed used most by geologists in mapping that area. This bed, or more properly the group in which this bed occurs, can be traced, with the

[1] T. S. Lovering, H. A. Aurand, C. S. Lavington, and J. H. Wilson, "Fox Hills Formation of Northeastern Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 7 (July, 1932), p. 702.

exception of a few short breaks, from northeastern Weld County along the east side of the Denver Basin and into the Colorado Springs Quadrangle. The writer has seen it in a few places on the west side of the basin and others report that it can be recognized along the west side and extending into northern Colorado.[1] About 60 feet above this horizon, in the Greasewood area, is a hard, brown, fossiliferous sandstone which varies from a few inches to 4 or 5 feet in thickness. This bed is a good marker in the Greasewood area, but disappears eastward. The dark gray shales above it contain an abundance of *Pteria nebraskana* and some *Foraminifera*. Above these shales, which average about 25 feet in thickness, oyster beds and sandstones, buff in the lower part and white at the top, come into the section. The white sandstone at the top averages 50 feet or more in thickness around the basin. Dobbin and Reeside[2] inferred that this sandstone, which was formerly called basal Laramie in eastern Colorado, correlated with the Colgate sandstone, the topmost member of the Fox Hills of eastern Montana. Although in many places it contains an abundance of fresh-water fossils at its top, the writer has collected marine fossils 10 feet above it in the Greasewood area. In one place in the Jimmie Camp area a conglomerate with black chert pebbles up to one inch in diameter occurs between the white sandstone and the buff sandstone below, whereas in other places in the same area an ironstone conglomerate occurs at the same position. This white sandstone, however, together with the underlying group of sandstones and sandy concretion beds, constitutes a mappable unit that can be followed a considerable distance and can be recognized easily in the logs of wells. However, no division can be made in well logs, in the majority of cases, between the white sandstone and the brown sandstones immediately underlying it.

The Fox Hills sandstone seems to rise in the section and feather out eastward and northeastward from Greasewood away from the source of the sediments. The distinguishing characteristics and even the fossils rise higher in the section between the Greasewood and the New Raymer areas. North and northeast of New Raymer pinks and reds come into the Fox Hills and into the Transition zone below. Whether this coloration is due to conditions of deposition or to contact with the pink and red clays of the White River (Tertiary) formation is not definitely known, although it is probably from the latter. From the evidence along Pawnee Creek, in eastern Weld County, it is cer-

[1] V. J. Hendrickson and others, personal communication.

[2] C. E. Dobbin and J. B. Reeside, Jr., "The Contact of the Fox Hills and Lance Formations," *U. S. Geol. Survey Prof. Paper 158b* (1929), p. 23.

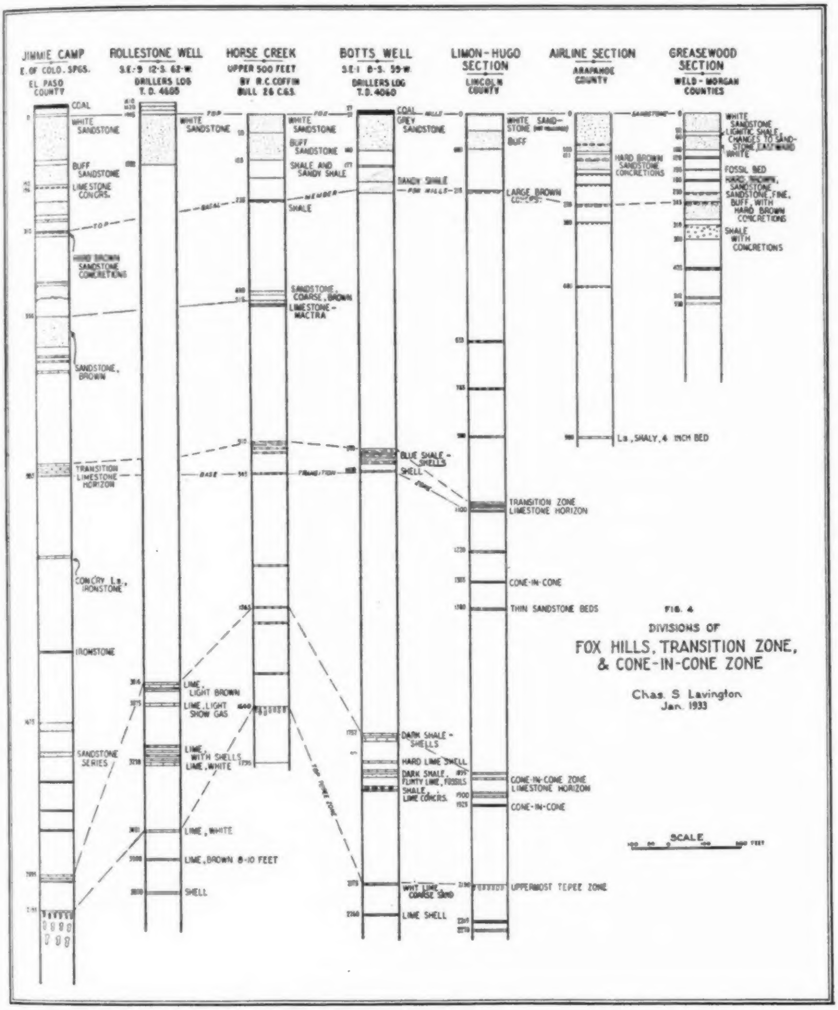

FIG. 4.—Divisions of Fox Hills, Transition zone, and Cone-in-Cone zone.

tain that the Fox Hills-Pierre terrain was considerably dissected at the time of White River deposition. Therefore, these pink and red clays being in contact with a considerable area of Cretaceous beds, both vertically and laterally, could easily color a considerable thickness of the more porous sandy beds of the Cretaceous by downward and laterally moving meteoric waters. These red and pink beds contain the usual marine fauna. Following is a partial list of fossils found in the Fox Hills, as identified by Junius Henderson and John B. Reeside, Jr.

Cardium speciosum	*Microbacia americana*
Dentalium gracile	Coral
Mactra alta	*Pholodomya subventricosa*
Tancredia americana	Gastropod (unidentified)

KEY BEDS

The different zones previously described are of practical use as regional horizon markers, and some of the beds or groups of beds within these zones are excellent local markers. The Fox Hills sandstone contains local markers in the Greasewood and New Raymer areas and even southward. These markers, although subject to some lateral variation both in character and thickness, can be followed for considerable distances. The big sandy concretion member in the basal part is especially valuable as a regional marker on account of its persistence. Although not so widespread as some of the others, the two limestone series mentioned, especially the one at the base of the Transition zone, make very good markers for both regional and local mapping.

In the Fountain area and southeastward towards Boone there is a remarkably persistent group of brown limestone beds in the Tepee zone that serves as an excellent marker. This group of beds is distinguished by its brown color and peculiar habit of weathering; that is, breaking into platy pieces at right angles to the bedding planes. The top of this group lies about 50 feet below the top of the lower 500 feet of the zone. A similar group in a similar stratigraphic position is present in the Florence and Cañon City areas.

As local markers, especially in pitting and shallow core drilling, and possibly as regional markers, the bentonite beds are useful. C. H. Rankin and the writer collected about thirty samples of bentonite from different localities and from beds which were thought to be correlative. These samples were studied by Warren O. Thompson at the University of Colorado as to their optical and physical properties and colloidal habits. It was found that on a basis of these properties, especially the relative amounts of heavy minerals and their respective

optical properties, correlations could be confirmed. The bentonite beds are especially helpful in determining the displacement and character of faults in which they are involved. In some areas faulting is abundant, and, although the vertical displacement rarely exceeds 15 feet, some faults with throws of 50 feet or more have been noted. The faults are of both the normal and reverse types. There seem to be two sets of faults, the major set having an average strike of N. 65° W., which parallels a long line of old folding to the south, and a minor set having an average strike of N. 40° E., the two thereby forming angles of 75° and 105° with each other.

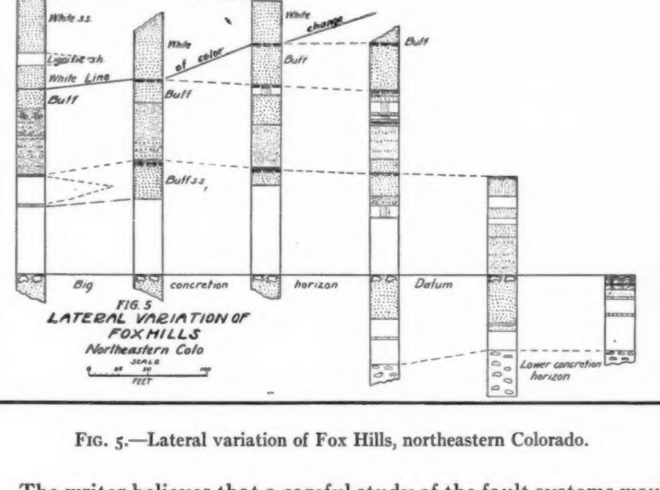

FIG. 5.—Lateral variation of Fox Hills, northeastern Colorado.

The writer believes that a careful study of the fault systems would aid in working out the structure of portions of the plains area where dips and strikes are erratic.

As a regional marker, the Tepee zone, being the most conspicuous zone, is probably the best of those described. As shown on the map (Fig. 2), its outcrop delineates the southern part of the Denver Basin and also indicates local structure. The most unusual feature of this zone, however, is the almost constant interval between it and the Dakota sandstone. It was first noted that this interval in two widely separated wells was practically the same, and that it checked closely with outcrop measurements some distance away in the Cañon City

Embayment. After that an outcrop measurement made in the Walsenburg Basin was found to check closely with the other intervals, which were 2,640 feet for the wells and 2,700 feet for the outcrop measurements. Later V. J. Hendrickson measured a section south of the Black Hills and found the interval there to be 2,700 feet, and Herman F. Davies reports it to be about 2,800 feet in southeastern Montana. This almost constant interval is remarkable in that the underlying zones of the Pierre, the Niobrara, and Benton formations all change considerably between these widely separated areas.

SUMMARY

It is the writer's belief that: (1) the Montana group of eastern Colorado can be divided into several definite zones; (2) these zones, which are recognizable at different localities, are, in some places, mappable units; (3) these zones contain some excellent horizon markers; and (4) the Fox Hills as now defined is a usable, mappable unit at the top of the Montana group.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 4 (APRIL, 1933), PP. 411-421, 2 FIGS., 1 PLATE

CHARACTERISTICS OF OLDER CRETACEOUS FORMATIONS OF NORTHEASTERN COLORADO[1]

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ABSTRACT

The following article presents the most evident physical characteristics of the older Cretaceous sediments which have been encountered by wells drilled in northeastern Colorado. On the basis of these characteristics, observed largely with the aid of a microscope, it has been possible to correlate the sediments with a considerable degree of accuracy throughout the area. The members of the Benton formation which are commonly evident in outcrops, could not be recognized in the well samples with any degree of certainty, but the changes in character of the sediments in this formation did permit its subdivision into a calcareous and a non-calcareous member. The members of the other formations all showed quite distinct differences in physical character.

INTRODUCTION

The older Cretaceous formations which are discussed in this paper include those from the top of the Niobrara formation to the base of the third or lower sand of the Dakota group as shown in Table I.

TABLE I

CRETACEOUS	Niobrara	Apishapa shale
		Timpas limestone
	Benton	Carlile sandstone*
		Carlile shale
		Greenhorn limestone
		Graneros shale
	Dakota group	1st sand
		2nd sand
		3rd sand

* Equivalent to Codell or "Niobenton" sandstone.—Editor.

To obtain the information which forms the basis of this paper, samples were examined from ten wells in the Greasewood and Fort Morgan areas, one well in the Wellington field, and two wells in the Wray area. In addition, the drillers' logs of the Willard well in Logan County and the Kelly well in Lincoln County were used to show relationships of the formations north and south of the Greasewood and Fort Morgan areas. Inasmuch as the lithological characteristics of the sediments under consideration are sufficiently different to admit of the recognition of individual members, and also to make possible satis-

[1] Manuscript received, December 24, 1932.

[2] Colorado School of Mines.

factory correlations of beds encountered in the wells, detailed study has been limited to these characteristics. A description of the microfaunas present in the older Cretaceous sediments was not undertaken during this investigation because, even though the microfaunas may prove to be of considerable importance for the recognition of certain horizons, they should be studied separately.

The tabulated depths to, and the thicknesses of, the older Cretaceous formations shown in Figure 1 have been determined from well samples wherever samples were available, but because the sample sets were not complete for all of the wells, it has been necessary to complete the table from drillers' records. The assistance given by Harry A. Aurand, who has been closely associated with the activities in this region, was of great aid to the writer in the interpretation of drillers' records. Although some cores were available for examination, the depths indicated in Figure 1, other than depths from drillers' records, have been determined from sample cuttings returned by the circulating fluid in "rotary" wells, or from those bailed out of "standard" wells.

The graphic correlation shown in Figure 2 indicates not only the relationships of the beds under discussion, but also the thickness of the Timpas limestone and the distance in feet of each formation below the base of the Timpas limestone, which has been adopted as the datum plane. The "top" of the Timpas is based on the first appearance of white limestone. Further details regarding the Timpas will be given in the description of this member.

DESCRIPTION OF FORMATIONS

NIOBRARA FORMATION

The Niobrara formation has been divided into two members: an upper member, known as the Apishapa shale, and a lower member, the Timpas limestone. The Apishapa shale was not examined in detail during this investigation; however, the portions observed consisted primarily of grayish black laminated shale and dark gray calcareous shale with light gray to white specks. The speckled shale is in many places so highly calcareous that it might be considered an argillaceous limestone. Some of the grayish black laminated shale is non-calcareous, but the greater part is somewhat calcareous. In general, the Apishapa shale can be distinguished from the overlying Pierre shales by its marked increase in calcareous content and decrease in sand content. The thickness of the Apishapa shale in the Greasewood and Fort Morgan areas will probably be found to be about 200 feet, whereas the thickness farther west is approximately 400 feet. In the

DEPTHS TO AND THICKNESSES OF THE OLDER CRETACEOUS FORMATIONS ENCOUNTERED IN WELLS IN NORTHEASTERN COLORADO

Figures followed by D from driller's records—all others from sample determinations

		Weld Co. Colo. Prairie O.&G. O'Toole No. 1 33-7N-62W	Weld Co. Colo. Greeley Oil Gadbois 1B 25-6N-61W	Weld Co. Colo. Reiter-Foster Johnson-Juhl 14-6N-61W	Weld Co. Colo. Cont. Oil Co. Briggs No. 1 13-6N-61W	Weld Co. Colo. Reiter-Foster Ida Johnson 24-6N-61W	Weld Co. Colo. Platte Valley Ray Patterson 24-6N-61W	Weld Co. Colo. Cont. Oil Co. Gadbois 1 24-6N-61W	Morgan Co. Colo. Prairie O.&G. D. Mortier 2-5N-61W	Morgan Co. Colo. Colo. Assoc. Pumphrey 14-4N-58W	Morgan Co. Colo. I. T. I. O. State No. 1 16-1N-57W	Logan Co. Colo. N.E. Colo. Oil State No. 1 36-8N-55W	Larimer Co. Colo. Union Oil Cal. Mitchell No. 1 6-9N-68W	Lincoln Co. Colo. Kelly Oil Co. State No. 1 36-14S-57W	Yuma Co. Colo. Cont. Oil Co. 28-2S-43W	Yuma Co. Colo. Phillips (Rosencrans) 3-2S-42W
Niobrara (Timpas)	Top T. D.	6760	6228D	6255	6250	6205	6212	6250	6025	5330	5134	4760D	3640	2935	1990	1970
	T.	40	37	25	21	45	48	20	40	30	43	40	22	40	60	75
	Base T. D.	6800	6265D	6280	6271	6250	6260	6270	6065	5360	5177	4800D	3662	2975	2050	2045
Benton	T.	290		280		290	314	302			277		388			
	Top "M" D.	7090		6560?		6540	6574	6572			5454		4050			
	T.	100		100		97	92	94			118		130			
Dakota Group	Top 1st D.	7190	6674	6660D	6639D	6637	6666	6666	6454	5758D	5572	5200D	4180			
	T.	23	16	38	36	41		31	36	22	27	27	36	For lower sands see Plate III	For lower sands see Plate III	For lower sands see Plate III
	Base 1st D.	7213D	6690D	6698	6675D	6678D		6697	6490D	5780D	5599D	5227D	4216D			
	T.	59		58					42	53	55	67				
	Top 2nd D.	7272D		6756					6532	5833	5654	5294				
	T.			158						194	149	124				
	Base 2nd D.			6914						6027	5803D	5418				
	T.									86	100	140				
	Top 3rd D.									6113D	5903D	5560D				
	T.									62		30				
	Base 3rd D.									6175		5590D				
	D. Last Sample	7200	6681	6918	6400	6642	6655	6690	6569	6176		5418	4210		2880	5130
	T. D.	7272	6698	6918	6675	6678	6666	6701	6588	6176	5905	5610	4216		2885	

W. A. Waldschmidt.

FIG. 1

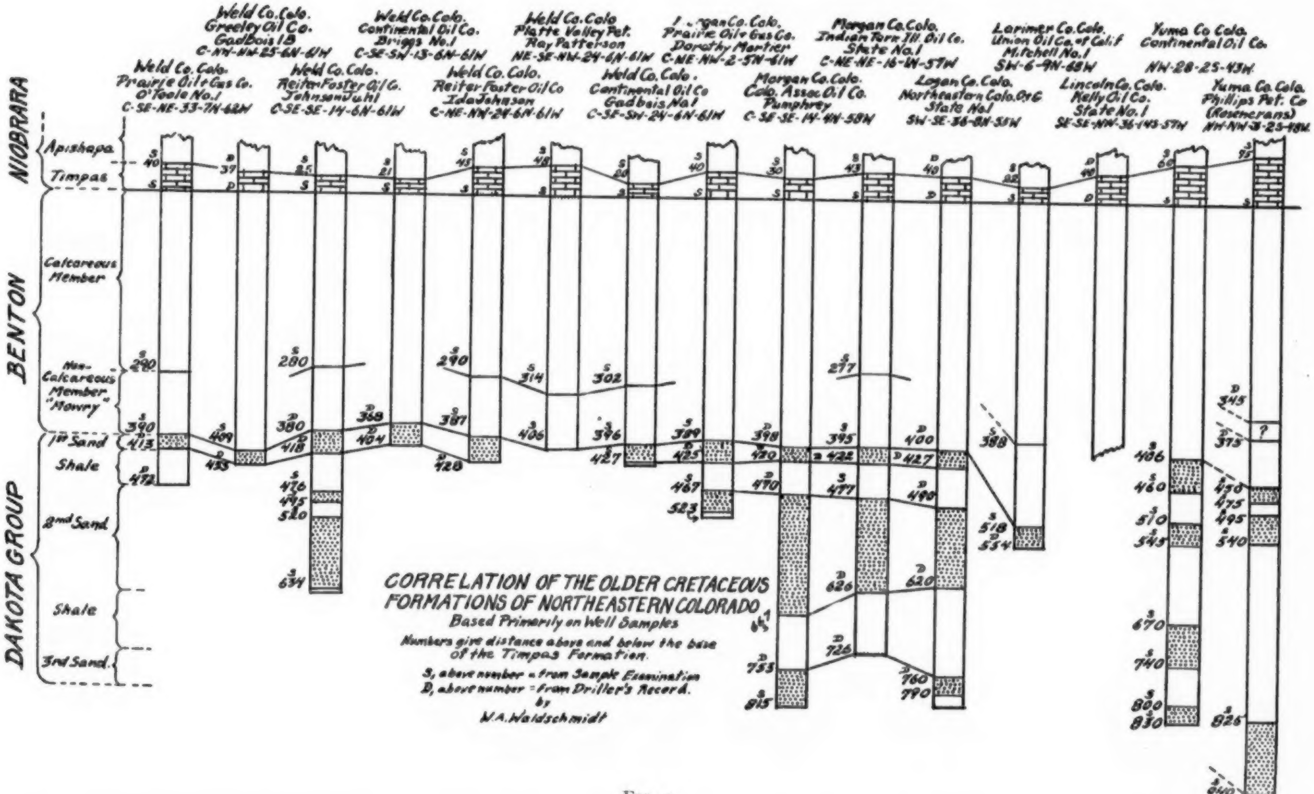
CORRELATION OF THE OLDER CRETACEOUS FORMATIONS OF NORTHEASTERN COLORADO
Based Primarily on Well Samples
Numbers give distance above and below the base of the Timpas Formation.
S, above number = from Sample Examination
D, above number = from Driller's Record.
by
W.A. Waldschmidt
NIOBRARA
Apishapa
Timpas
BENTON
Calcareous Member
Non-Calcareous Member "Mowry"
DAKOTA GROUP
1st Sand
Shale
2nd Sand
Shale
3rd Sand
Weld Co. Colo. Prairie Oil & Gas Co. O'Toole No. 1 C-SE-NE-33-7N-62W
Weld Co. Colo. Greeley Oil Co. Gadbois 1B C-NW-NW-25-6N-61W
Weld Co. Colo. Reiter-Foster Oil Co. Johnson-Juhl C-SE-SE-14-6N-61W
Weld Co. Colo. Continental Oil Co. Briggs No. 1 C-SE-SW-13-6N-61W
Weld Co. Colo. Reiter-Foster Oil Co Ida Johnson C-NE-NW-24-6N-61W
Weld Co. Colo Platte Valley Pet. Ray Patterson NE-SE-NW-24-6N-61W
Weld Co. Colo. Continental Oil Co Gadbois No. 1 C-SE-SW-24-6N-61W
Prairie Oil & Gas Co. Dorothy Mertier C-NE-NW-2-5N-61W
Morgan Co. Colo. Colo. Assoc. Oil Co. Pumphrey C-SE-SE-14-4N-58W
Morgan Co. Colo. Indian Terr. Ill. Oil Co. State No. 1 C-NE-NE-16-1N-57W
Logan Co. Colo. Northeastern Colo. O & G State No. 1 SW-SE-36-8N-55W
Larimer Co. Colo. Union Oil Co. of Calif. Mitchell No. 1 SW-6-9N-68W
Lincoln Co. Colo. Kelly Oil Co. State No. 1 SE-SE-NW-36-14S-57W
Yuma Co. Colo. Continental Oil Co. NW-28-2S-43W.
Yuma Co. Colo. Phillips Pet. Co (Rosencrans) NW-NW-3-2S-48W

FIG. 2

Wray area a still greater thickness may be expected because speckled shales and *Foraminifera* of Niobrara types have been found at least 600 feet above the top of the Timpas limestone.

The Timpas limestone, which is a persistent bed throughout eastern Colorado, is an excellent horizon marker. It varies in color from white through grayish white to pale buff. *Foraminifera* are abundant in the Timpas limestone, and because of their transparency they give the more dull white limestone a speckled character. The upper part of the Timpas limestone is relatively soft, and in some places it approaches the consistency of hard chalk. Approximately, the lower 20 feet of the Timpas is relatively hard and commonly breaks into flat fragments when drilled by rotary tools. Practically all of the samples from the Timpas limestone contain some shale with Apishapa characteristics. This shale may be from the true Apishapa member, although a part of it may be from thin shale members within the Timpas limestone itself.

The thickness of the Timpas limestone in ten wells in the Greasewood and Fort Morgan areas varies from 20 to 48 feet, is only 22 feet in the Mitchell well in the Wellington field near the foothills, and reaches a thickness of 60–75 feet in the Wray area. The hard, lower portion of the limestone is apparently about 20 feet in average thickness. This portion has not yet been definitely separated in the samples from the overlying, more chalky limestone, but when such a separation is made, it may be found that the lower hard portion is comparable with the Timpas limestone as observed in outcrops.

BENTON FORMATION

The Benton formation has been subdivided into the Carlile, Greenhorn, and Graneros members by geologists who have studied this formation at its outcrops. In all described sections which the writer has studied, and in those sections which he has examined at the outcrops, the three named members are evident, but unfortunately the same breaks could not be found with any degree of accuracy in all of the wells from which samples were examined. Samples from the Mitchell well in the Wellington field contain gray Carlile sand through an interval of 20 feet, the base of which is at a depth of 3,680 feet. This sand consists of relatively uniform-sized grains with maximum diameters ranging from 0.18 to 0.21 millimeter. The grains are largely angular, but a few show a slight degree of rounding. Samples from the Ray Patterson well in the Greasewood area contain a Carlile sand immediately below the Timpas limestone. This sand extends from 6,260 to 6,265 feet, in depth. It is gray, compact, and streaked with

black shale. The grains are angular, uniform in size with maximum diameters of 0.18–0.21 millimeter. It is also slightly calcareous. A thin sand is present in samples from the Ida Johnson well in the Greasewood area. This sand, with characteristics similar to the Carlile sand in the Ray Patterson well, is mixed with Timpas limestone, but although it probably underlies the Timpas, it has been shown on the graphic log (Fig. 2) as a part of the limestone. The interval containing the sand is about 6 feet thick. In the three Carlile sandstones just described, small rounded grains of glauconite are present in small amounts. Some biotite is also present in the Carlile in the Mitchell well.

In the remaining wells in the Greasewood and Fort Morgan areas, no definite Carlile sandstone was found immediately below the Timpas limestone, but sand grains and small fragments of the sand were found down to 70 feet below the base of the Timpas. The driller's record of the Willard well in Logan County shows Carlile sandstone from 4,784 to 4,790 feet, and the Kelly well in Lincoln County records Carlile sandstone from 2,975 to approximately 3,000 feet. In the two wells in Yuma County, near the eastern border of Colorado, the Carlile sandstone is entirely absent or at most represented by a slightly sandy shale immediately below the Timpas limestone.

The interval between the Carlile sandstone and the Dakota group could not be subdivided, as stated before, into definite Greenhorn and Graneros members, but a general subdivision into two parts was possible. The upper part of the two divisions is designated as the calcareous member, which in Figure 1 and Figure 2 includes the Carlile sandstone. The lower part is designated as the non-calcareous member or "Mowry." A rather marked variety of sediments is present in the "calcareous" member. These consist of grayish black shale, dark gray shale, brownish gray and gray limestone, and dark gray speckled shale. The grayish black shale is very fine textured, massive to poorly laminated, and usually calcareous. The dark gray shale is massive, fine textured, and slightly gritty. It contains minute micaceous particles, occasional small black specks of organic material, and it slacks readily in water. The greatest interval of the massive shale was observed in the Indian Territory Illuminating Oil Company's well between 5,288 and 5,360 feet. In the other wells the shale was not confined to any definite horizon. The dark gray speckled shale is massive, relatively hard, and very calcareous. Some of the fragments might be considered as argillaceous limestone, although in most of them the calcareous content is due largely to the specks which are in part foraminifers or fragments of foraminifers. Dark gray is the dominant

color of the speckled shale, but faint brownish shades also may be observed. The brownish limestone was found in all of the wells in the "calcareous" member, but not in horizons definite enough to admit of accurate correlations. This limestone is slightly crystalline, fossiliferous, massive, of medium-grained texture, and possesses a distinctive brownish vitreous luster. These characteristics distinguish the limestone readily from the white limestone of the Timpas, and definitely place it in the Greenhorn. A good bed of the Greenhorn limestone was encountered in the Ray Patterson well between 6,328 and 6,338 feet, but similar limestones found in the other wells could not be definitely correlated with this. Bentonite, brown concretionary fragments, and pyrite are present in the "calcareous" member, but no attempt was made to determine whether these materials were confined to definite horizons.

The thickness of the "calcareous" member in the Greasewood and Fort Morgan areas was found to range from 280 to 314 feet, whereas its thickness in the Wellington field was determined to be 388 feet. It must be remembered that the thicknesses of the calcareous member include all sediments from the base of the Timpas limestone to the top of the non-calcareous member.

The non-calcareous member lies between the base of the calcareous member and the top of the 1st Dakota sand. It consists of a dense, black, non-calcareous fissile shale. Fish remains are relatively abundant, but are not uniformly distributed. This shale is very similar to the Mowry shale of Wyoming. Some shale with Mowry characteristics was observed in the calcareous member above, but in this no fish remains were observed. The thickness of the non-calcareous or Mowry member in the well samples examined ranges from 92 to 118 feet in the Greasewood and Fort Morgan areas, and increases to 130 feet in the Wellington field.

An approximate determination of the contact between the calcareous and non-calcareous members can be made by dropping small grab samples into hydrochloric acid, and observing the point at which effervescence decreases noticeably. Such testing should not be relied upon too much because often the non-calcareous shale is mixed with a large portion of the overlying calcareous shales.

DAKOTA GROUP

The Dakota group can be divided into the 1st or upper sand, the 2nd or middle sand, and the 3rd or lower sand, with intervening shales. The 1st sand, which has frequently been called the "Muddy," is light gray, tightly cemented, and very vitreous on fresh surfaces. The

grains are variable in size, reaching a maximum diameter of 0.45 millimeter. The variation in size is more noticeable in the sand from different wells than in several samples of the sand from any single well. Most of the grains are angular, but some of the larger grains show a considerable amount of rounding. A large number of the grains are transparent, but dull white and grayish grains are in large enough quantity to give the sand a light gray color (Pl. I, Fig. 1). Black chert grains, mica flakes, magnetite, and glauconite grains are present, but only in very small numbers. In core samples the interstratification of the sand with grayish black shale is very pronounced (Pl. I, Fig. 5). The thickness of the 1st sand of the Dakota group, as determined from samples, ranges from 22 to 41 feet. The average thickness from all determinations, except for the sand in the Greeley Oil Company's Gadbois well No. 1B, is approximately 32 feet.

The 2nd sand of the Dakota group is decidedly different in character from the 1st and 3rd sands. Its grains are colorless, transparent, vitreous, angular to round, and variable in size. The larger grains vary from 0.45 to 0.60 millimeter in diameter, and because of their abundance the sand as a whole is coarser than either the 1st or 3rd sands (Pl. I, Figs. 2 and 3). Another characteristic which aids in the recognition of the 2nd sand is the secondary enlargement of the grains by the addition of quartz and the development of crystal faces. Still another outstanding characteristic of this sand is the dull white, kaolin-like cementing material. This material is present in sufficient quantity to deaden the highly vitreous luster of the individual grains, and give fresh surfaces of the sandstone a less vitreous luster than that of the 1st sand, in which the grains are less transparent, and in which the kaolin-like material is not present.

The thickness of the 2nd sand seems to be variable, but whether or not this variation is due to poor samples, or to actual changes of thickness in the bed could not be determined. The best samples available are from the Colorado Associated Oil Company's Pumphrey well, in which 194 feet of the sand was cored. In the Reiter Foster Oil Company's Johnson-Juhl well, the sand is 158 feet thick, and in the Indian Territory Illuminating Oil Company's State well No. 1 it is 149 feet thick. In the Northeastern Colorado Oil Company's well the sand was logged by drillers as 124 feet thick.

The 3rd sand of the Dakota group was penetrated by the Colorado Associated Oil Company's Pumphrey well, and found to be 62 feet thick. Cores from this sand are in appearance much like the cores from the 1st sand, particularly in that the sand is interbedded with thin black shale streaks.

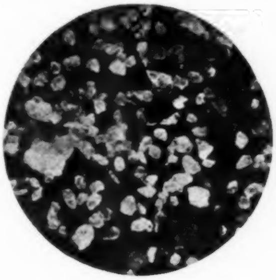

FIG. 1

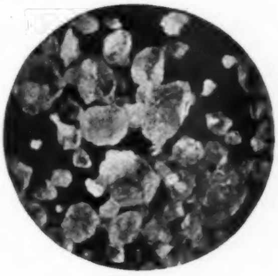

FIG. 2

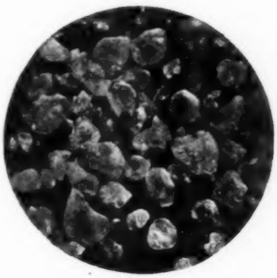

FIG. 3

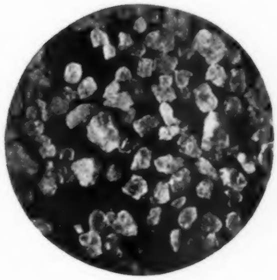

FIG. 4

FIG. 5

FIG. 1.—1st Dakota sand: ×20; Colorado Associated Oil Co., Pumphrey well; depth 5,758 feet.

FIG. 2.—2nd Dakota sand: ×20; Colorado Associated Oil Co., Pumphrey well; depth 5,778 feet.

FIG. 3.—2nd Dakota sand: ×20; Colorado Associated Oil Co., Pumphrey well; depth 5,835 feet.

FIG. 4.—3rd Dakota sand: ×20; Colorado Associated Oil Co., Pumphrey well.

FIG. 5.—Core of 1st Dakota sand, showing interlaminated black shale. Original core about 3 inches in diameter.

The sand is vitreous on freshly broken surfaces, and is made up of angular, variable-sized grains about intermediate in size between the 1st and 2nd sands (Pl. I, Fig. 4).

CONCLUSIONS

This investigation has not only proved to the writer's satisfaction that for practical purposes satisfactory correlations can be made of some of the older Cretaceous beds of northeastern Colorado on the basis of lithological characteristics of the sediments, but it has also proved that rotary samples are not always reliable for correlation of beds which are only a few feet in thickness, such as the Carlile sandstone and the Greenhorn limestone.

During this investigation a considerable amount of information was obtained relative to the reliability of rotary samples for correlative purposes, and it is hoped that this information, together with the results of further work which is now in progress, may be published as soon as completed.

A summary of the lithological characteristics of the various sediments is not necessary, but the variations in thickness and the extent of the beds will be reviewed briefly.

The Timpas limestone, which is such a persistent bed throughout northeastern Colorado, was found to vary from 20 to 75 feet on the basis of samples. These thicknesses include all of the interval in which white limestone was observed, consequently the top of the Timpas limestone may in reality represent the top of a series of thin, chalky white limestones which overlie a true hard white Timpas limestone about 20 feet in thickness. Regardless of whether or not the Timpas limestone as represented in Figure 2 can be subdivided into a lower, hard limestone and an upper series of thin-bedded, chalky limestone, the increase in thickness of the limestone from the Mitchell well in Larimer County to the Rosencrans well in Yuma County is 53 feet. In the Greasewood and Fort Morgan areas the average thickness is 35 feet, and in Logan and Lincoln counties it is 40 feet. In general, the Timpas limestone horizon increases gradually in thickness toward the northeast, the east, and the southeast borders of the Denver-Greeley basin.

The Apishapa shale has not yet been thoroughly investigated, but from casual examinations it appears that this shale will show a slight decrease in thickness from the western side of the basin to the Greasewood and Fort Morgan areas, and a marked increase in thickness from there eastward to Yuma County.

The "Mowry" shale, which overlies the 1st Dakota sand, is quite

consistent in thickness throughout the area embraced by the wells from which samples were examined.

The sands of the Dakota group, with the exception of the 1st or upper sand, show a considerable variation in thickness, but since most of the wells penetrated only the 1st sand, information regarding the continuity of the 2nd and 3rd sands is meager. A very noticeable variation takes place in Yuma County, where the sands of the Dakota group are relatively thin and the intervening shales have greatly increased in thickness.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 4 (APRIL, 1933), PP. 422-432, 1 FIG.

STUDY OF WELL SECTIONS IN NORTHEASTERN COLORADO[1]

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Denver, Colorado

ABSTRACT

In northeastern Colorado the Pierre shale is divisible into three groups which can be carried into central Colorado. It is suggested for the present that Lower, Middle, and Upper Pierre might be sufficiently descriptive, but more definite nomenclature is justified. The name Hygiene is definitely associated with the Middle group. The distinct difference between the Lower and Upper groups also seems to justify greater distinction, and it is proposed that either a new name be applied to the Upper group or that the name Lewis shale be applied to its equivalent. If the name Lewis is applied to the upper shale member of the Pierre, the name Steele is suggested for the Lower group between the Hygiene group and the top of the Niobrara.

INTRODUCTION

The completion of the Patterson oil well by the Platte Valley Petroleum Corporation, in the Greasewood field, Weld County, Colorado, in October, 1930, and the drilling of 13 other wells in surrounding areas since that time have made available data on a part of Colorado on which there has heretofore been but little subsurface information. In this paper the writer offers an interpretation of the results of these borings.

ACKNOWLEDGMENTS

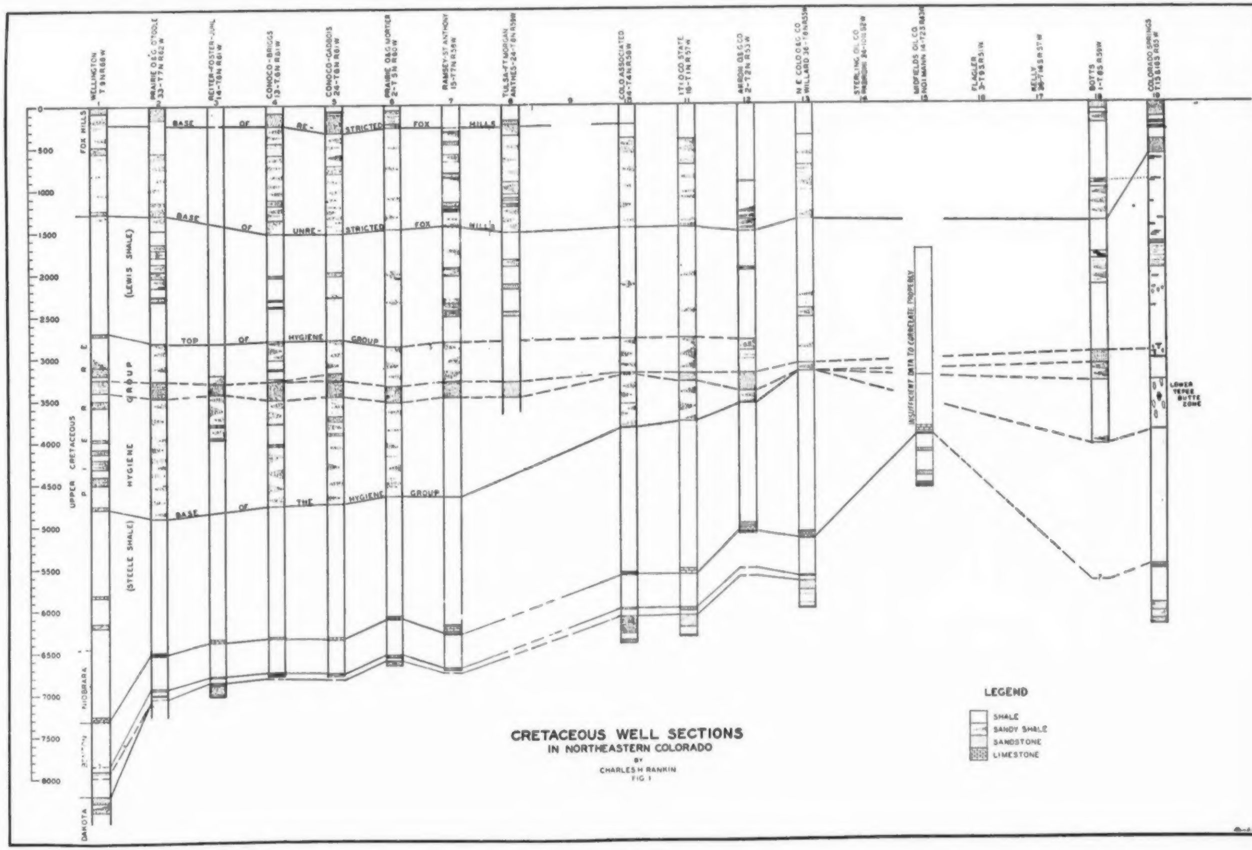
The writer is indebted to the Continental Oil Company for the opportunity to examine well cuttings and to publish the results. All the oil companies operating in the area have kindly exchanged information and samples. He is indebted to Charles S. Lavington for measured sections and correlations of wells outside of the area discussed, and to V. J. Hendrickson for suggestions and criticism of the manuscript. Walter Krampert's sample log of the Mortier well to a depth of 1,800 feet is used in this paper.

SOURCES OF INFORMATION

The information used in preparing the sections (Fig. 1) with the single exception already noted, was obtained by examining more than

[1] Manuscript received, January 26, 1933. Published with the permission of the chief geologist, Continental Oil Company.

[2] Geologist, Continental Oil Company.



WELLINGTON T 9N R68W
PRAIRIE O&G O'TOOLE 33-T7N R62W
REITER-FOSTER-JUHL 14-T6N R61W
CONOCO-BRIGGS 13-T6N R61W
CONOCO-GADBOIS 24-T6N R61W
PRAIRIE O&G MORTIER 2-T5N R60W
RAMSEY-ST ANTHONY 15-T7N R58W
TULSA-FT MORGAN ANTHES-24-T6N R59W
COLO ASSOCIATED 24-T4N R58W
IT'L O CO STATE 16-T1N R57W
AKRON O&G CO 2-T2N R53W
N E COLO O&G CO WILLARD 36-T6N R53W
STERLING OIL CO
MIDFIELDS OIL CO
FLAGLER 3-T9S R51W
KELLY
BOTTS 1-T8S R58W
COLORADO SPRINGS
FOX HILLS
UPPER CRETACEOUS
PIERRE
NIOBRARA
DAKOTA
BASE OF RE-STRICTED FOX HILLS
BASE OF UNRE-STRICTED FOX HILLS
(LEWIS SHALE)
TOP OF HYGIENE GROUP
HYGIENE GROUP
(STEELE SHALE)
BASE OF THE HYGIENE GROUP
INSUFFICIENT DATA TO CORRELATE PROPERLY
LOWER TEPEE BUTTE ZONE
LEGEND
SHALE
SANDY SHALE
SANDSTONE
LIMESTONE
CRETACEOUS WELL SECTIONS
IN NORTHEASTERN COLORADO
BY
CHARLES H RANKIN
FIG 1

FIG. I

5,000 well samples. Core information and drillers' logs also were used. Information concerning wells drilled prior to 1930 is from published records and other sources. Surface work in the area and surface correlations also were used in interpreting the results of drilling.

All the wells from which samples were taken, with the exception of the Tulsa-Fort Morgan Petroleum Corporation's Anthes No. 1, were drilled by rotary methods, and in examining the samples allowances were made for many factors which are not considered when examining bailer samples. The speed of drilling, pump pressure, and strokes per minute, thickness of the drilling fluid, amount and nature of open hole, and specific gravity of the cuttings being returned, as well as other factors, affected the interpretation of the samples. Variations in making allowances for these various factors cause the results of independent workers to differ in detail but it is believed that similar conclusions are generally reached.

NOMENCLATURE

The strata in northeastern Colorado herein described comprise the Dakota group, Benton shale, Niobrara formation, Pierre shale, Fox Hills sandstone, and Laramie formation, all of Upper Cretaceous age. The Fox Hills has recently been restricted in eastern Colorado to include only the well defined sandstones and interbedded shales in the upper 300 feet of the 1,200–1,500 feet of section formerly included in that formation and still included in it along the mountain front. The Patterson sand is the producing horizon in the Greasewood field and is tentatively correlated with the Muddy sand of drillers. The middle sand is called the Dakota, and the name Lakota is applied to the third sand penetrated in the Colorado Associated well, although it is possible that additional information may disprove this correlation.

The only new nomenclature proposed is a subdivision of the Pierre shale into zones.

DESCRIPTION OF FORMATIONS

DAKOTA GROUP

The Dakota group of eastern Colorado commonly consists of three sandstones of varying thickness, separated by shale. The sandstones are herein called, in ascending order, Lakota, Middle Dakota, and Upper Dakota. Along the mountain front the Lakota and Middle Dakota are separated by variegated shale, which, however, is not present, so far as known, in eastern Colorado. The Middle and Upper Dakota are separated by micaceous gray shale in part sandy and non-calcareous. The Upper Dakota is the Muddy sand of other writers.[1]

[1] Kirtley F. Mather, James Gilluly, and Ralph G. Lusk, "Geology and Oil and Gas Prospects of Northeastern Colorado," *U. S. Geol. Survey Bull. 796-B* (1928).

COLORADO GROUP

Benton shale.—The Benton shale in eastern Colorado consists of dark gray to black shale with the Codell or "Nio-Benton" sandstone member at its top. The Benton in northeastern Colorado consists of a basal 100-foot non-calcareous, siliceous phase (Mowry), an intermediate calcareous member, and an upper dark shale containing numerous limestone concretions grading upward into sandy shale or sandstone at the top. That part of the Benton above the Mowry phase has a thickness of 300 feet or more, and the thickness of the entire Benton varies from 400 to more than 500 feet. The subdivisions of the Benton in southeastern Colorado are Graneros shale, Greenhorn limestone, and Carlile shale.[1]

Niobrara formation.—The Niobrara formation includes about 300 feet of chalky calcareous shale and interbedded limestone, having at its base the Fort Hays or Timpas limestone member, which in this area ranges in thickness from 23 to 35 feet. The top of the Niobrara could not be sharply defined by the well samples. As it is ordinarily difficult to determine the contact even in good outcrops, some of the variations in thickness which have been ascribed to this formation may be thus explained.

MONTANA GROUP

Pierre shale.—The Pierre shale includes from 2,500 to 6,000 feet of shale, sandstone, sandy shale, concretionary limestone, and numerous bentonite beds. The formation thins eastward from the Front Range in northern Colorado, as the result, in part, of depositional thinning, and in part, of erosion from the top. The Pierre may be divided into three main divisions, and Lavington has shown that other divisions are possible farther south. In general, the lower 1,000 feet consists mainly of non-sandy shale. The Middle group includes the sandy Hygiene group of the mountain front, and the Upper consists of silts and thin beds of shale with many sandstones and sandy zones. The upper half of the sandy zone is known as the Transition zone, because it contains both Fox Hills and Pierre fossils, as well as a distinctive fauna of its own.

Fox Hills sandstone.—The Fox Hills sandstone has two definitions in the area described. Along the mountain front it includes the Transition zone and has a thickness ranging from 1,000 to 2,000 feet, with the Milliken sandstone member at the top. In northeastern Colorado, to facilitate areal mapping, the Fox Hills has been restricted, as sug-

[1] G. K. Gilbert, *U. S. Geol. Survey Geological Atlas, Pueblo Folio 36* (1897).

gested by C. E. Dobbin and John B. Reeside, Jr.,[1] to include only the sandstones and interbedded shales in the upper 300 feet of the formation as previously defined. This restriction is based on the definition of the formation at its type locality, in spite of the fact that many fossils formerly restricted to the Fox Hills range downward for several hundred feet. The restriction was adopted as a result of a field conference held by the Rocky Mountain Association of Petroleum Geologists and the Northeastern Colorado Scouts Association.

LARAMIE FORMATION

Laramie beds consisting of sandstone, shale, coal, and many fossil beds of variable thickness overlie the Fox Hills in this area, but are not discussed herein.

DESCRIPTIONS OF WELL SECTIONS

The location of the measured sections and the wells described herein are shown on Figure 2 of Lavington's paper.

1. *Wellington.*—The Wellington section (Fig. 1, No. 1) is a composite section which includes a surface measurement from the top of the Fox Hills down to the surface at a well plus well logs to the base of the section. The log from the Muddy sand down to the base of the Lakota is that of the Scott well No. 3 of the Continental Oil Company. The combined section gives a total thickness of 8,400 feet for the Upper Cretaceous, exclusive of the Laramie, and is only approximately correct because of possible errors in surface measurements. It is believed, however, to be more nearly correct than the Fossil Creek section measured about 20 miles farther south. The Wellington section is given in order to compare the northeastern Colorado plains sections with the section along the mountain front.

2. *Prairie Oil and Gas Company's O'Toole well No. 1.*—This well starts in the Laramie 280 feet above the Laramie-Fox Hills contact, as determined by surface measurements and well samples. The samples were very good and that part of the log above the Niobrara is an excellent reference for correlating other wells in northeastern Colorado. The Patterson sand should have been encountered at the depth reached, but in spite of the fact that the lower 60 feet was cored, poor recovery of cores and a caving hole prevented its identification. It is possible that the sand is not developed to the extent that it is in the Greasewood field. If the Patterson sand is not present at this location, it is probable that the producing horizon in the Fort Collins field is not equivalent to that in the Greasewood field.

[1] C. E. Dobbin and J. B. Reeside, Jr., "The Contact of the Fox Hills and Lance Formations," *U. S. Geol. Survey Prof. Paper 158-B* (1929).

The thickness of the Fox Hills (restricted) is given as 270 feet, although it is possible that the sandstone encountered between 200 and 270 feet is Fox Hills. The samples were lost from 490 to 740 feet and the base of the formation was determined by correlating with other wells. The Transition beds have a thickness of 1,490 feet and consist of interbedded sandstone, shale and sandy shale. The shales are very gritty and with few exceptions are siltstones. All the material is very fine. Below the Transition beds are 1,350 feet of siltstone with a few sandy layers. These sandy layers seem to be very persistent and may be recognized in other wells. Bentonite beds and pyrite are common in the lower half of this section. The Hygiene group has a thickness of 2,080 feet, and the sandstone which has been referred to by workers in the field as the "Hygiene" is encountered 450 feet below the top of the group. This sandstone has a thickness of about 200 feet and is composed of poorly sorted quartz grains, angular to sub-angular, with many heavy minerals and glauconite. It contains a large proportion of finer materials and is cemented with a calcareous cement. The principal basis for the recognition of this sandstone in the rotary samples is the sharp increase in the size of the sand grains. The strata both above and below are sandy, but with few exceptions the sand grains are all much smaller. This sandstone is shown on Figure 1, and is probably correlative with one of the upper members of the Hygiene group, either the Rocky Ridge or the Larimer, of the Wellington area. There seems to be more evidence that it is the former. Below this sandstone is a 75-foot black fissile shale that seems to be very persistent, although it is not always recognized in samples. The next 1,355 feet consists mainly of interbedded sandstone, sandy shale, siltstones, non-gritty shale, concretionary limestones, and bentonite seams. As the Pierre-Niobrara contact is difficult to fix with certainty, no attempt has been made to determine it and the lower Pierre is therefore grouped with the Niobrara. The thickness of the combined group is 1,600 feet, of which the lower third or less is probably Niobrara. The basal limestone of the Niobrara was cored and its thickness was 35 feet. The Benton section is apparently normal, with a thickness of about 410 feet.

3. *Reiter-Foster Oil Corporation's Johnson-Juhl well No. 1.*—This well was drilled to a total depth of 6,918 feet and penetrated 162 feet into the Dakota group. The top of the Fox Hills occurs about 80 feet above the well.

4. *Continental Oil Company's Briggs well No. 1.*—The top of the Fox Hills is about 90 feet above the well. As the log of this well is typical of all adjoining wells, other wells are not described. The well

penetrates 150 feet of the restricted Fox Hills, 1,280 feet of Transition beds, and 1,265 feet of silty shale between the Transition beds and the top of the Hygiene group. The Hygiene group has a thickness of 1,960 feet and the top of the "Hygiene sand" is 475 feet below the top of the group. The interval from the base of the Hygiene group to the base of the Niobrara, which was cored in this well, is 1,575 feet. The thickness of the Benton group is 409 feet.

5. *Continental Oil Company's Gadbois well No. 1.*—This well has a log almost identical with that of the Briggs well a mile farther north, and is presented only to show the similarity of well records in the Greasewood field.

6. *Prairie Oil and Gas Company's Mortier well No. 1.*—This well, although slightly higher in surface elevation, is believed to start at the same stratigraphic horizon as the Briggs No. 1. The peculiarity of this well is that although the section above the Hygiene group is approximately 100 feet greater than encountered in the near-by Greasewood wells, the section below the Hygiene group is considerably less and the thinning of the Hygiene group is equal to the thinning of the entire Upper Cretaceous section, exclusive of the Laramie. Although there is no other evidence of faulting, that condition is suggested by the well record.

7. *Ramsey Brothers's St. Anthony well No. 1.*—The St. Anthony well commences at the top of the Fox Hills and reaches the Patterson sand at a depth of 6,680 feet, giving a total thickness for the Upper Cretaceous section of 7,105 feet. The thinning of the Hygiene group accounts for all of the thinning in this well.

8. *Tulsa-Fort Morgan Petroleum Corporation's Anthes well No. 1.*—The bottom of the Anthes well is at a depth of 3,380 feet, the "Hygiene sandstone" having been encountered at a depth of 3,190 feet. The well commences 70 or 80 feet below the top of the Fox Hills and the section above the "Hygiene" sandstone does not show appreciable change in thickness.

10. *Colorado Associated Oil Company's Pumphrey well No. 1.*—This well commenced 250 feet below the top of the Fox Hills and was abandoned at a total depth of 6,176 feet, having reached a varicolored shale (Morrison?), indicating a total thickness of 6,400 for the Upper Cretaceous. The top of the Hygiene group was encountered at 2,550 feet, indicating a thickness of 2,800 feet for the interval between the top of the Fox Hills and the top of the Hygiene group, the same as noted in the O'Toole well. The thickness of the group, however, is 1,050 feet, as compared with 2,075 feet in the O'Toole well. This thinning, 1,025 feet, is slightly greater (50 feet) than the entire thinning

of the Upper Cretaceous from the O'Toole well to the Associated well, a distance of 29.4 miles.

11. *Indian Territory Illuminating Oil Company's State well No. 1.*—The I.T.I.O. well section was taken partly from the I.T.I.O. sample log (0–3,640 feet) and from samples furnished the writer. This composite log is correlated accurately with the Associated well and suggests that only slightly more than 400 feet of the upper part of the Upper Cretaceous below the Laramie has been eroded.

12, 13 and 15. The Akron, Willard and Midfields wells are correlated as shown by the use of drillers' logs.

18. The Bott's well is correlated as shown in Figure 1. The record is from drillers' log and in part from sample examination by John S. Wilson.

19. *Colorado Springs section.*—The section shown in Figure 1 as No. 19 is a surface section measured by Charles S. Lavington to the top of the Phillips Petroleum Company well, and includes the log of that well through the Dakota group. It shows the relations which exist at the south end of the Denver Basin and the changes which have taken place. From the section, it appears that the Fox Hills (unrestricted) is somewhat thinner, and that the Tepee zone is the time equivalent of at least part of the Hygiene group on the north. There is some evidence that the Tepee zone of the Colorado Springs section correlates with the surface beds near the Midfields well. This correlation, however, is only tentative.

CORRELATION OF SECTIONS

In nearly all the sections shown in Figure 1, the top of the Fox Hills has been determined by surface measurements and correlations. The base of the restricted Fox Hills is more or less arbitrary, and in many of the wells which commence in the Fox Hills no samples were available upon which to make a determination. The base of the unrestricted Fox Hills is drawn at the base of the lowest sandy member in the Transition zone. The top of the Hygiene group in all sections is the highest sandy member below the upper shale member of the Pierre. There are, as has been mentioned, several sandy members in the Upper Pierre, but fortunarely the lower portion of the Upper Pierre is very free of sandstone. This simplifies the recognition of the top of the Hygiene group. The base of the Hygiene group is drawn at the base of the lowest sandstone lying above the lower shale member of the Pierre.

No attempt is made to differentiate the Lower Pierre and the Upper Niobrara. There is, however, a distinct difference in the lime

content of the Niobrara and Pierre shales which might be used in the determination of the contact. The base of the basal limestone of the Niobrara is the bottom of that formation. In northeastern Colorado there is no shale between the Niobrara and the Codell sandstone member, and in some well cores which show the contact the limestone grades into shaly sandstone in a vertical interval of less than a foot.

Positive evidence as to whether or not the Patterson sand belongs in the Benton group is lacking. The base of the Dakota group is drawn at the top of the variegated shale which underlies the lowest sandstone member of the group. Only four wells in eastern Colorado have penetrated this variegated shale and samples are available on only one of these, the Colorado Associated Oil Company's Pumphrey No. 1. It is possible that the variegated shale is correlated with a similar red shale occurring between the Dakota and Lakota along the mountain front. If such is the case, none of the wells discussed has penetrated the Lakota sand.

HISTORICAL GEOLOGY

In this area, as elsewhere in the west, the advance of the Cretaceous sea is recorded by the character of the Dakota group. The succeeding Benton time was one in which shales were uniformly deposited in eastern Colorado. A rather sharp increase in the thickness toward the west *may* point to a source of material in that direction, although it may represent only a basinward movement. The deposition of the Codell sandstone member seems to mark the close of Benton time in the area, although it is possible, in spite of the fact that the uniformity of thickness is opposed to such an interpretation, that other strata may have been deposited and eroded. The Codell sandstone cores taken in the area suggest wave action, if not shoreline conditions. Farther south, Johnson[1] found evidence of an unconformity, or at least a time hiatus between the Benton and Niobrara.

A uniform Niobrara section occurs in the Greasewood area. The basal limestone member is particularly uniform in character and thickness.

Pierre time opened with the deposition of a basal shale member in which pyrite is common, and with a sharp decrease in the lime content. The thickness of the basal shale member seems to be uniformly about 250 feet. The next succeeding period of shale deposition was closed by the ingress of sandy materials into a sea in which little, if any, sand had previously been carried. This period also marks the close of a long

[1] J. Harlan Johnson, "Unconformity in Colorado Group in Eastern Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), p. 789.

era in which there was little, if any, diastrophism or deformation in this region, or elsewhere in the west.

The ingress of sandy materials postulates a positive element, probably westward, which is closely allied with the source of the Mesaverde sediments of southwestern Colorado. The entire period during which the Hygiene sediments were deposited reflects the influence of this positive element and the group is one in which sandstone and sandy shale predominate. The thickness of the Hygiene group is variable as shown by Figure 1.

Two explanations may be offered for the variation in thickness of the Hygiene group from west to east: (1) proximity to sources of sediment may account for a thicker Hygiene group on the west, and (2) a basin was being developed along the line of the present mountains contemporaneously with the development of the positive element on the west. The answer to the question as to which of these explanations is correct lies in the interpretation of areas outside of the scope of this paper.

The upper part of the Pierre was deposited during a period in which little sand was being carried into the Pierre sea. The sediments of this period, though principally of silt size and finer, are almost entirely siliceous. There are occasional strata in which there is a slight increase in the sand grain size and others which are non-gritty clays. The thickness of the upper part of the Pierre shale is, as might be expected from its character, notably uniform.

Pierre time was closed by a second invasion of sandy materials which marks the beginning of the "Transition" period. During "Transition" time the deposition consisted mainly of fine silty sandstones and interbedded shales. The Pierre seas were withdrawing and the change in the character of the sediments is accompanied by a change in the fauna.

Fox Hills deposition consisted mainly of near-shore marine sandstones with occasional shales. While it is true that in general the Fox Hills sandstones are noticeably coarser than the underlying Transition strata, they are very much finer than the overlying Laramie sandstones.

The thickness of the Upper Pierre, Transition, and Fox Hills strata is notably uniform and the top of the Fox Hills is conformable with the top of the Hygiene group throughout northeastern Colorado.

Thus, it is apparent that surface structure outlined by the upper Pierre and Fox Hills beds reflects subsurface conditions with only the modifications due to the eastward thinning of the Hygiene group.

SUMMARY AND CONCLUSIONS

This paper shows that in northeastern Colorado the Pierre shale is divisible into three groups, and that these groups can be carried into central Colorado. It is suggested that, for the present, Lower, Middle, and Upper Pierre might be sufficiently descriptive, but that more definite nomenclature is justified.

The name Hygiene is definitely associated with the Middle group. The distinct difference between the Lower and Upper groups also seems to justify greater distinction, and it is proposed that either a new name be applied to the Upper group or that the name Lewis shale be applied to its equivalent.

If the name Lewis is applied to the upper shale member of the Pierre, the name Steele is suggested for the lower shale group between the Hygiene group and the top of the Niobrara.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 4 (APRIL, 1933), PP. 433-435, 1 FIG.

PRESENT DEVELOPMENT IN GREASEWOOD AREA, WELD AND MORGAN COUNTIES, COLORADO[1]

HARRY A. AURAND[2]
Denver, Colorado

The discovery well of the Greasewood field was drilled by the Platte Valley Petroleum Corporation as Patterson No. 1, located in the NE., C., SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 24, T. 6 N., R. 61 W. It was drilled with cable tools and was commenced on May 6, 1926. It was completed at a depth of 6,661 feet on October 10, 1930, with an initial production of 100 barrels per day from the Muddy sandstone of Upper Cretaceous age. It was later deepened 30 feet. This well produced a total of 133,700 barrels of oil to February 1, 1933, and averaged 43 barrels per day for the month of January, 1933.

The table shows a condensed history of the operations.

[1] Manuscript received, February 9, 1933.

[2] Stanolind Oil and Gas Company, First National Bank Building, Denver.

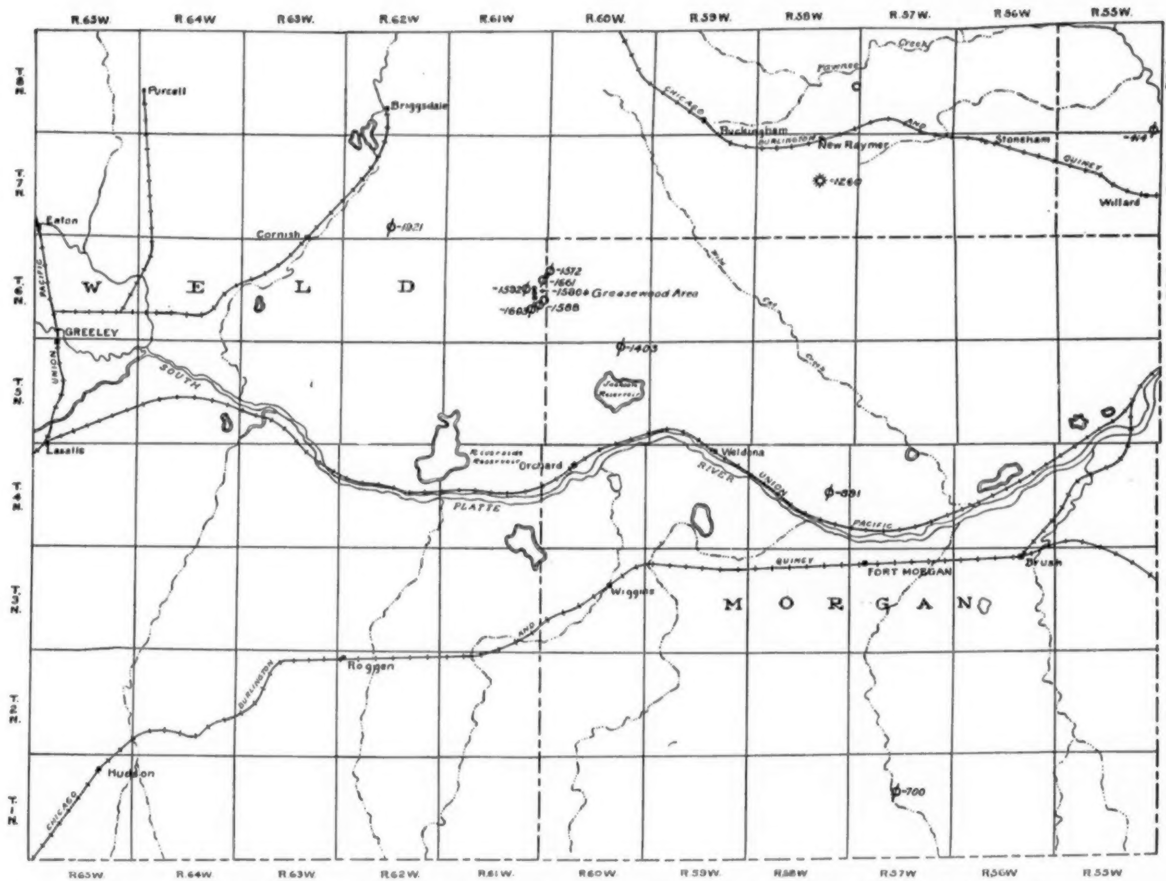


FIG. 1.—Sketch map of part of northeastern Colorado, showing location of Greasewood area. Structural elevation, base of Timpas limestone (Niobrara-Cretaceous). Width of each township and range, approximately 6 miles.

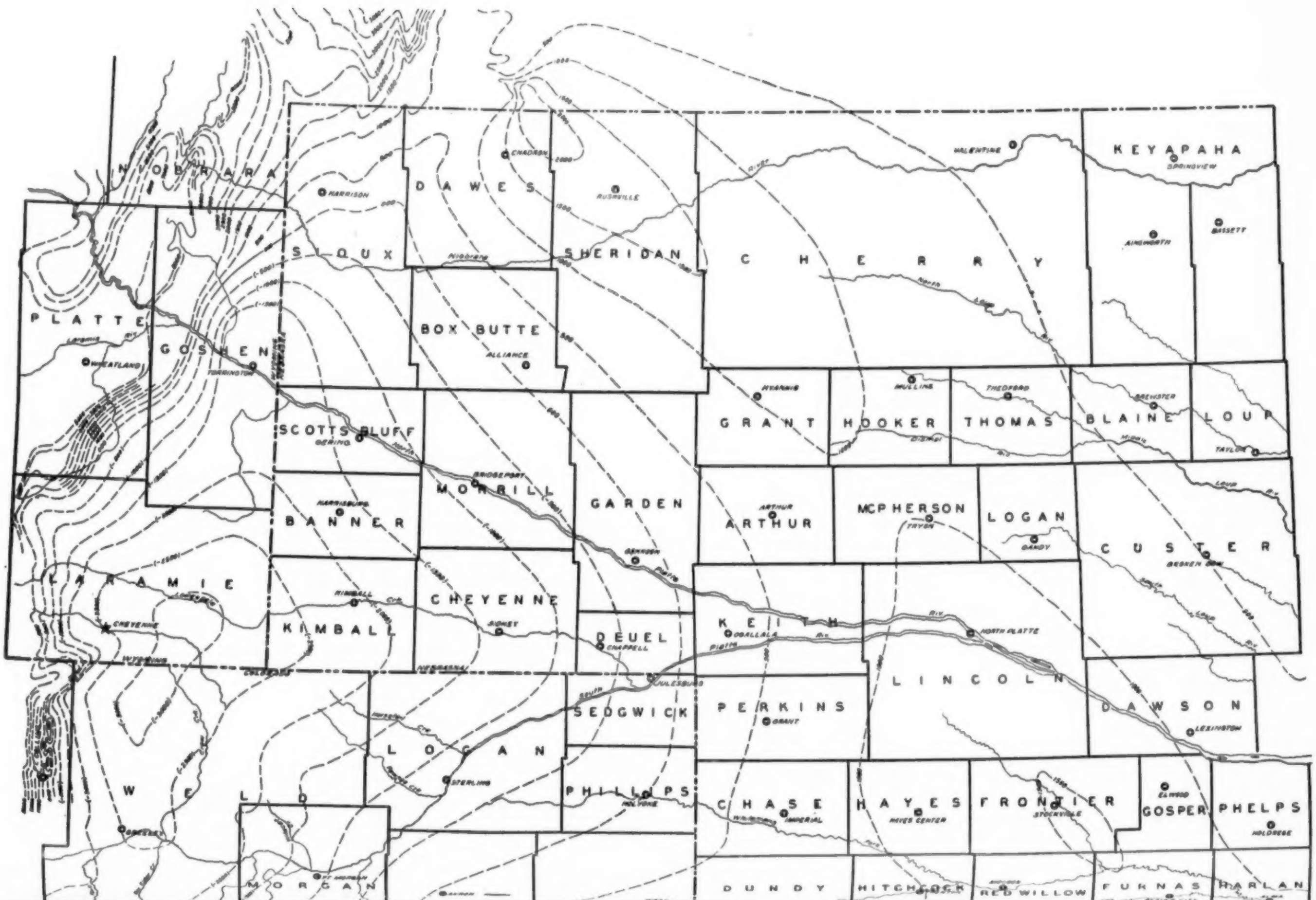
FIG. 1.—Sketch map of part of northeastern Colorado, showing location of Greasewood area. Structural elevation, base of Timpas limestone (Niobrara-Cretaceous). Width of each township and range, approximately 6 miles.

HISTORY OF PRODUCTION
GREASEWOOD POOL, WELD COUNTY, COLORADO*

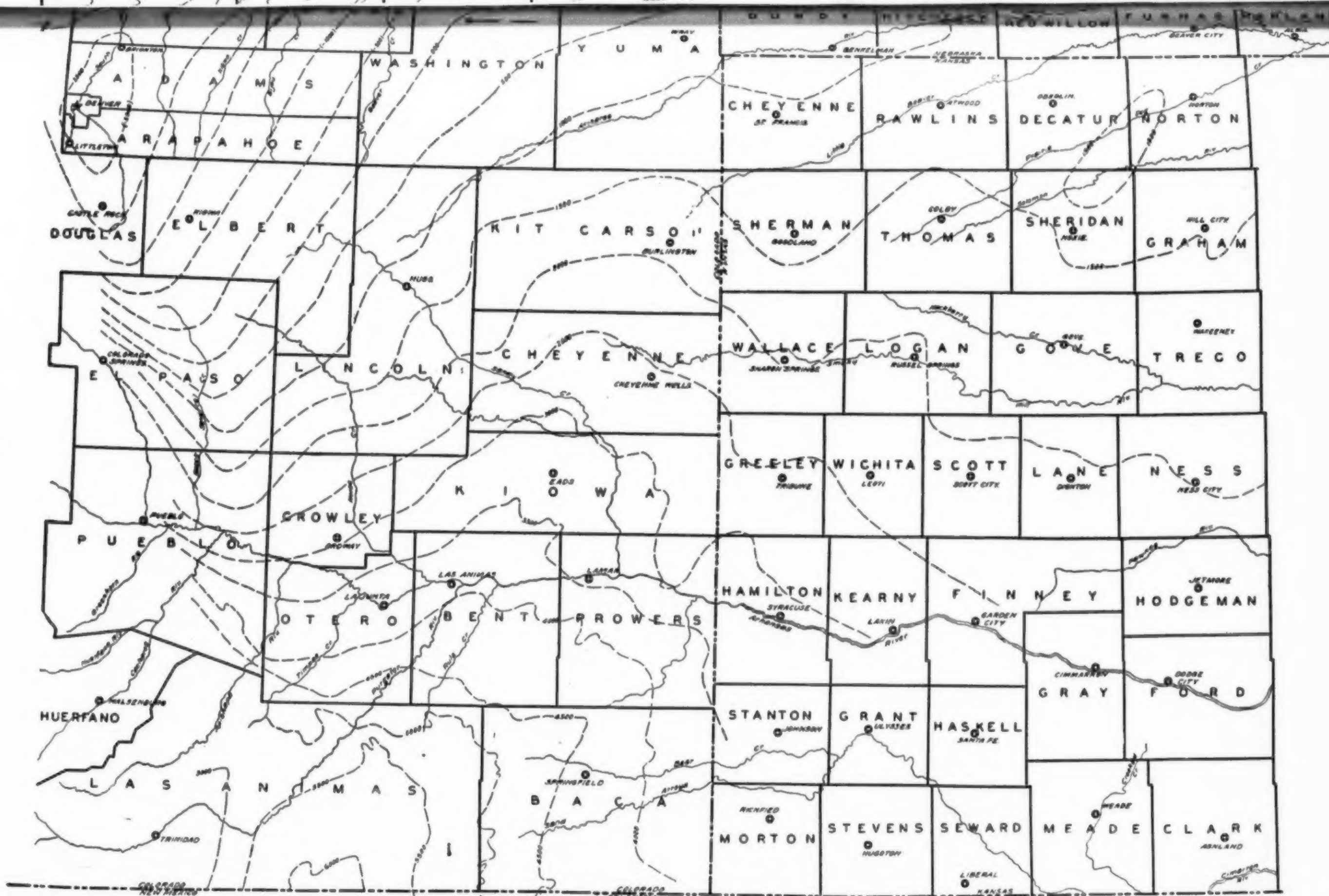
Company	Well	Location Sec., T., R.	Date Commenced	Date Completed	Total Depth (Feet)	Initial Prod. (Barrels)	Total Production in Barrels 1930	1931	1932	Jan., 1933	Total to 2/1/33	Daily Aver. Jan., 1933	Remarks
DEVELOPMENT WELLS													
Platte Valley Petrol. Co.	Patterson 1	24- 6-61	5/ 6/26	10/10/30	6,691	100	13,782	97,109	21,465	1,332	133,688	43	
Reiter-Foster Oil Co.	Ida Johnson 1	24- 6-61	5/ 7/31	8/25/31	6,678	808	..	31,142	27,191	1,596	58,333	51	
Continental Oil Co.	Briggs 1	13- 6-61	8/ 1/31	10/ 4/31	6,675	414	..	42,374	58,902	3,024	104,300	98	
							13,782	170,625	107,558	5,952	296,321		
Reiter-Foster Oil Co.	Johnson-Juhl 1	14- 6-61	8/19/31	3/31/32	6,918	Dry							
Continental Oil Co.	Gadbois 1	24- 6-61	8/ 4/31	2/ 4/32	6,701	35							Produced only small amount of oil
Greeley Oil Co.	Gadbois 1	25- 6-61	9/12/31	3/31/32	6,698	10							Produced only small amount of oil
Ohio Oil Co.	Butters 1	7- 6-60	6/20/32	11/25/32	6,683	..							Swabbing few barrels oil from Muddy at irregular intervals. Plugged back from 6,756.
Continental, *et al.*	Niles 1	13- 6-61	6/20/32	..	6,721	Dry							May drill to Sundance
Reiter Foster-Platte Valley Petrol. Corp.	Wm. Wilson 1	24- 6-61	10/ 8/31	..	840	..							Standing
OTHER WELLS IN VICINITY													
Prairie O. & G. Co.	O'Toole 1	33- 7-62	11/ 8/31	2/ 5/32	7,273	Dry							
Ramsey Bros.	St. Anthony 1	15- 7-59	9/ 8/32	..	6,769	Gas†							Produced small amount of oil from top of Dakota. Plugging back to complete as gas well.
Tulsa-Ft. Morgan	Anthes 1	24- 8-59	5/ ?/32		3,318								Mead Bros. rigging up rotary to resume for Continental and California Co.
Prairie O. & G. Co.	Mortier 1	2- 5-60	10/13/31	1/29/32	6,488	Dry							
Colo. Assoc. Oil Co.	Pumphrey 1	14- 4-58	9/ 5/31	1/10/32	6,176	Dry							

* Prepared by R. Clare Coffin.

† 6,000,000 cubic feet.



NIOBRARA
PLATTE
GOSHEN
LARAMIE
SIOUX
DAWES
SHERIDAN
BOX BUTTE
SCOTTS BLUFF
BANNER
KIMBALL
MORRILL
CHEYENNE
GARDEN
DEUEL
CHERRY
KEYAPAHA
GRANT
HOOKER
THOMAS
BLAINE
LOUP
ARTHUR
MCPHERSON
LOGAN
CUSTER
KEITH
LINCOLN
DAWSON
PERKINS
SEDGWICK
PHILLIPS
LOGAN
WELD
MORGAN
CHASE
HAYES
FRONTIER
GOSPER
PHELPS
DUNDY
HITCHCOCK
RED WILLOW
FURNAS
HARLAN
WHEATLAND
TORRINGTON
CHEYENNE
HARRISON
CHADRON
RUSHVILLE
ALLIANCE
VALENTINE
SPRINGVIEW
AINSWORTH
BASSETT
GERING
BRIDGEPORT
KIMBALL
SIDNEY
OSHKOSH
CHAPPELL
OGALLALA
NORTH PLATTE
JULESBURG
STERLING
HOLYOKE
GRANT
IMPERIAL
HAYES CENTER
STOCKVILLE
ELWOOD
HOLDREGE
LEXINGTON
BROKEN BOW
GANDY
TRYON
ARTHUR
HYANNIS
MULLINS
THEDFORD
BREWSTER
TAYLOR



Structure map of eastern Colorado and parts of adjacent states. Generalized structure contours on top of Dakota sandstone. Contour interval, 500 feet. Width of area mapped, east-west, approximately 300 miles.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 4 (APRIL, 1933), PP. 438-443, 1 FIG.

GEOLOGICAL NOTES

NOTES ON AN OCCURRENCE OF GALENA AT PIERCE JUNCTION SALT DOME, HARRIS COUNTY, TEXAS[1]

There are numerous references in the literature to the occurrence of galena, sphalerite, hauerite, and other metallic sulphides associated with the salt domes of the Gulf Coast Province, but these, for the most part, refer to occurrences within the cap-rock zone rather than in the associated sedimentary rocks around the domes. For this reason another note[2] on the occurrence of galena within the sedimentary rocks rather than in the cap-rock zone seems worth recording.

A core from the Kouri-Grayburg Bender No. 1, located on the northwest side of the Pierce Junction salt dome, Harris County, Texas, from a depth of 4,120 feet, contains galena.

The core is a light gray sandstone, nearly homogeneous except for lime and galena cement. The sand grains are sub-angular and have an average diameter ranging from 0.25 to 0.42 millimeter. The galena occurs as cementing material, and is of secondary origin. The sand was very porous previous to cementation. Many of the galena crystals terminate euhedrally in the pore spaces. Some individual crystals of galena are sufficiently large to include several sand grains.

Although no fossils were found in the suite of cores examined, the well at this point was penetrating steeply dipping beds of middle Tertiary age. Horizontally the 4,120-foot point is, at most, only a few hundred feet from the periphery of the salt.

Several origins are possible for deposits of galena. In these salt-dome occurrences, however, an igneous or metamorphic origin is highly improbable, if not entirely impossible. Transportation by water of slightly elevated temperature is possible, although no evidence has been found to suggest that such an elevated temperature was due to igneous activity. Even if igneous rocks should be found near these domes in the coastal belt, the occurrences of galena are too widely scattered for an igneous origin.

[1] With permission of the Gulf Production Company.

[2] Marcus A. Hanna, "Galena and Sphalerite in the Fayette at Orchard Salt Dome, Fort Bend County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 4 (April, 1929), pp. 384–85. *As the Fayette member of the Jackson Eocene is now restricted, this occurrence of galena and sphalerite at Orchard Dome should probably be placed in the Frio rather than in the Fayette.*

Two other main sources for the galena are possible, that is, the salt series itself, and the sediments surrounding the salt structures. The source of the galena of the cap-rock zone was probably either the salt series, or the surrounding sediments, since the cap-rock, primarily, is of residual origin[1] rather than a true bedded sedimentary material. Probably both the salt series and the sediments surrounding the salt structures contain a sufficient amount of lead to furnish the small amount required for these occurrences.

In his discussion of the galena and sphalerite at Orchard, Hanna[2] mentioned that there "are numerous beds composed almost entirely of volcanic ash" associated with the galena and sphalerite. Beds of volcanic ash are common in the middle Tertiary rocks of this area. The galena at Pierce Junction occurs within this general series of beds. Possibly these ash horizons may have been the source of at least a part of the galena and other metallic sulphides found in the sedimentary rocks surrounding these domes.

MARCUS A. HANNA
W. G. PARKER

HOUSTON, TEXAS
September 27, 1932

RECENT MOVEMENTS ON A FAULT OF BALCONES SYSTEM, McLENNAN COUNTY, TEXAS

In the flat bottom of the Bosque, north of Waco, Texas, there is an excavating machine which has been standing idle for two years. This machine stands as a monument to mark the spot where the new 42-inch cast-iron water main, rigid with leadite joints, crosses a member of the Balcones fault system. About once every 2 weeks, through a period of 18 months, it has been necessary to uncover the water main, which is about 20 feet underground, and replace a shattered joint in the immediate vicinity of the place where the brittle pipe crosses the fault plane.

With this pipe line breaking so continuously at that one place and nowhere else, there can hardly be any doubt that trembling shearing movements with possibly a little down-slipping along the fault plane are the cause of the trouble.

[1] Marcus I. Goldman, "Features of Gypsum-Anhydrite Salt Dome Cap-Rock," *Bull. Geol. Soc. Amer.*, Vol. 40 (1929), pp. 99–100. (Abst.)

Marcus A. Hanna, "Secondary Salt-Dome Materials of the Coastal Plain of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 11 (November, 1930), pp. 1469–75, 1 pl.

[2] Marcus A. Hanna, *op. cit.* (1929), p. 385.

This brings up the interesting questions: how old is the Balcones fault system? when did the faulting first begin? and how much of it has taken place in comparatively recent time? In so far as this particular member is concerned, abundant facts are available which, no doubt, have a bearing on the case, and, possibly, tell the whole story.

Farther north, 10 miles from the place where the water main crosses, the fault has a surface throw of about 375 feet, bringing the Austin chalk (Upper Cretaceous) down against the Del Rio (Comanche), cutting out both the Eagle Ford and the Woodbine. At this point the fault is bracketed by two deep dry holes, both of which go through the Cretaceous and deep into the formations below. The west or upthrow well is what is known as the Ossenbeck well; it is located only a few hundred yards west of the surface trace of the fault. The downthrow well, known as the Harrington well, is about 3 miles east of the surface trace, near the center of a downfaulted block.

The logs of these wells[1] show some surprising discrepancies for two wells so close together. The Comanche section from the top of the Georgetown to the base of the Glen Rose, all marine limestones and chalky shales, is 1,140 feet thick in the upthrow. In the downthrow well this section is 1,150 feet thick, almost exactly the same. But in the Trinity (also Comanche), next below the Glen Rose, the story is different: the upthrow well had only 130 feet of Trinity sands and shales; the downthrow well, 445 feet of Trinity, 315 feet more than was found in the other well.

Below the Cretaceous, the upthrow well went from the Trinity sands directly into a 450-foot bed of hard black limestone; the downthrow well found 380 feet of pre-Cretaceous sandstones and shales between the bottom of the Trinity and the top of the same bed of hard black limestone.

In other words, the downthrow well found 700 feet of Trinity and pre-Trinity formations which were not present in the upthrow well. This 700-foot section might have been cut out by a pre-Glen Rose fault, which the upthrow well crossed at a depth of 1,540 feet from the surface, but that is hardly likely. Such a fault would have to be parallel with the present fault, which, with a downthrow toward the east, passes east of the upthrow well. It would also have had to die out before Del Rio time, as that formation is unbroken on the surface except in the one fault.

The logical conclusion, to this writer at least, is as follows. The

[1] The records here used are those published by W. S. Adkins, "Geology and Mineral Resources of McLennan County," *Texas Univ. Bull.* 2340 (1924).

present fault had a throw of 380 feet at the beginning of the Cretaceous era; during Trinity time, which was a period of great readjustments, the fault slipped 315 feet more; during the quiet time which followed, when the limestones and shales of the Glen Rose, Walnut, Comanche, Peak, Edwards, and Georgetown were being deposited, the fault remained inactive.

Since Georgetown time, we can see from the surface that there has been 375 feet more of faulting. When did that faulting take place? We have this suggestion: for about 15 miles along this fault there are superficial deposits of Pleistocene sand and gravel. West of the surface trace, on the upthrow side, the gravels occur in spots and only in a very thin veneer. On the east, on the downthrow side, they are in thick beds. At one place, in the White Rock Gravel Pits, 5 miles north of Waco, the thickness is more than 150 feet.

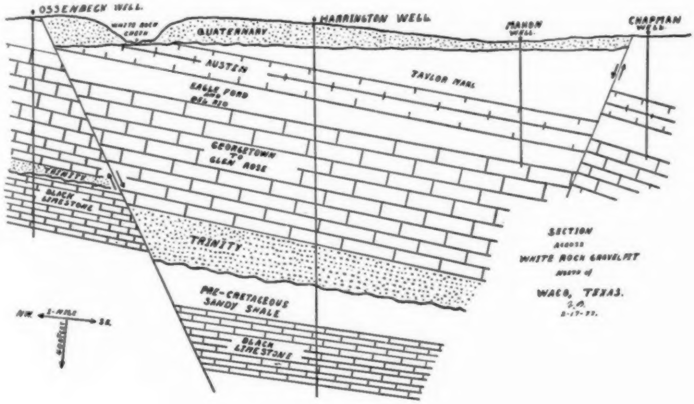


FIG. 1.

When it is understood that these exceptionally thick gravel deposits actually make one of the highest hills in that part of the country, and that they are found along the downthrow side of this fault and nowhere else, their presence becomes significant. It certainly suggests that at the time these thick gravel beds were being deposited, the downthrow fault block which they cover was sinking at a rapid rate. And, again, there must be some connection between the thick gravels and the faulting, for from the place where the fault crosses the Waco-Golson road to the town of West, a distance of 8 miles, the surface trace is for all practical purposes the west edge of this exceptionally large, upland gravel deposit. And since there is no other

such gravel deposit in this part of central Texas, this close association could hardly be an accident.

If these thick gravel deposits are the result of faulting during Pleistocene time, then the history of this fault would be as follows. The movement began in pre-Cretaceous time, about one-third of the faulting taking place then; a second third took place during Trinity time; following that era of great changes, there was a long period of rest which probably lasted until long after the Cretaceous era; the next active era came in mid-Pleistocene time. This last active era may not yet be ended, as the breaking water main suggests that faulting is still taking place.

FRANK BRYAN

3420 CHATEAU AVENUE
WACO, TEXAS
January, 1933

NOTES ON SUBMARINE GEOLOGICAL EXPLORATION

Airplane pictures, taken vertically downward from altitudes of 2,000 or 2,500 feet on bright days when the sea is comparatively quiet, facilitate the geological exploration of off-shore areas wherein one may suspect the occurrence of a "structure" and a buried stratigraphic horizon favorable for the production of oil. Decapitated folds at the sea bottom may possibly be revealed by uncovered exposures of upper strata. Many such exposures are submarine cliffs of 15–25 feet in height—cliffs which stand in valleys of loose sands and silts. They may be visible from the air because of their color, because of shadows which they cast, or because of seaweed, which, as we know, grows only with its roots attached to firm rock.

Such pictures, then, offer leads to follow on the floor of the sea. With a little practice a geologist becomes a good diver in shallow water. Rock samples are collected by prying off pieces with a pick or a short crow-bar, and the lay of the strata is observed in the usual way in dips and strikes by compass and clinometer. Points of location require two observers with transits conveniently placed on shore. Signals by flags are recorded by the observers and the geologist in consecutive numbers.

The amount of air in the diver's suit can be regulated in order to facilitate either locomotion or stance, both of which are of course essential in submarine geological work. In obtaining the samples, and in reading for dip and strike, the geologist should not bend over, but lie down preferably on one elbow. In this way he may again stand with his feet on the bottom. Air in the middle and lower portions of the

suit makes it difficult for him to obtain an erect position after bending over.

Often the geologist's work can be facilitated, or can be rendered in greater detail, by his use of a water-jet. This can be made of 2-inch pipe with a nozzle on the lower end and with a rubber-hose attachment at the top end. The length can be made to suit local conditions. Ordinarily such a pipe may range from 30 to 60 feet in length. A pump for water is operated aboard the accompanying tug. With such a jet exposures may be uncovered when not too much sand and silt overlie them. For more deeply buried rocks the jet can be pushed slowly downward. At bed rock pieces are likely to be washed up to the top of the hole. Samples may thus be obtained, but obviously the lay of the strata can not be observed.

All data which the geologist may obtain as to the depth of water, the thickness of sand or silt overlying the bed rock, and the nature of the bed rock itself, will be useful to the engineer whose duty it is to plan in a preliminary way for a pier and caisson foundation to accommodate a derrick, in case such a project is considered in the light of the geologist's report. Naturally the actual construction will require subsequent detailed study of submarine conditions by the engineer himself.

Stanley C. Herold
Geologist and engineer
Harold L. Fudge
Submarine engineer

Los Angeles, California
February 23, 1933

GAS ON MARYSVILLE BUTTES, SUTTER COUNTY, CALIFORNIA

The first well on the Marysville Buttes, which area was described by the writer in the April, 1932, issue of the *Bulletin*,[1] has come in as a gas well and the field is now proved. This well is in the upper part of the Cretaceous shales which abut the andesites of the Buttes and the well was gauged as a 3,000,000-cubic foot producer. A second well has already been located and will explore for slightly deeper production. This is the first well of its type, so far as I can ascertain, in the United States.

Walter Stalder

San Francisco, California
February 15, 1933

[1] Walter Stalder, "Structural and Commercial Oil and Gas Possibilities of Central Valley Region, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 4 (April, 1932), pp. 361–71. Author described relationship of the igneous core of the Buttes to the petroliferous Cretaceous rocks.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 4 (APRIL, 1933), PP. 444-446

REVIEWS AND NEW PUBLICATIONS

"*Études Géologiques et Prospections Minières par les Méthodes Géophysiques*" (Geologic Studies and Mining Prospecting by Geophysical Methods). By P. GEOFFROY and P. CHARRIN. *Bull. du Service de la Carte Géologique de l'Algerie*, 4 Ser., Géophysique, No. 1 (Alger, 1932). 346 pp., 103 figs. Paper. 6½ x 9⅞.

Here is a fairly complete survey of the practical uses of geophysics written for the executive or geologist confronted with the question of the best method to use on any particular problem. The material in this text is largely the result of the authors' practical experience with the methods discussed, rather than a compendium of geophysical methods compiled from library sources.

The work is divided into two parts. The first discusses in non-technical fashion the physical principles underlying the various methods, laying particular emphasis on the physical conditions necessary for their effectiveness.

The second part of the book is concerned with the practical application of the methods. It is divided by chapters considering each general type of geologic problem and the methods most effective in its solution. All emphasis possible has been placed on the need for careful interpretation of the results of a geophysical survey.

One very noticeable result of considering the geophysical methods from the viewpoint of practicability is the relegation of the magnetic method to a minor rôle with the comment that the difficulties of interpretation are so great that the cheapness of the method becomes apparent rather than real.

There is an obvious tendency to emphasize the various electric methods, especially resistivity and potential measurements. However, this is to be expected in a book devoted to mining as well as oil prospecting.

On the other hand, the discussion of seismic methods is not treated in sufficient detail. The authors freely admit this and acknowledge their unfamiliarity with the method. Most of their discussion is concerned with refraction shooting and only a few vague statements can be found concerning the reflection method.

As a result, they limit the application of the seismograph almost completely to salt domes. It is lamentable that a book of such usefulness as this should make no acknowledgment of the widespread use of the reflection method and that it should insist that enormous charges of dynamite are the chief factor in its cost and that such charges preclude the use of the method in any but sparsely populated areas.

A table is given showing salt domes discovered by various geophysical methods. Very few other data of a concrete nature are given concerning geophysical results. It would be highly desirable to list an authenticated account of the successes and failures of geophysics, and it would seem that such a listing might be possible at this time.

The final chapter is concerned with a comparison of the methods, both technically and economically, and a consideration of the depths attainable.

L. Y. Faust
Geophysical Research Corporation

Tulsa, Oklahoma
February 20, 1933

Directions for the Use of the Askania Torsion Balance. By C. A. Heiland. 88 pp., 33 figs., 7 photographs. American Askania Corporation, Houston, Texas (1933). Cloth. 6×9.

This attractive little book is far more comprehensive than its too specific title would indicate. It is not only a guide to the correct manipulation of the Askania torsion balances, but is, in fact, a summary presentation of the entire field of torsion-balance theory and practice.

By a treatment with differentials of class-room proved clarity, the theory is carried in the first chapter up to the fundamental torsion-balance formula. This is logically developed in Chapter II to the actual computation of gravity data from instrument records. Formulas are given for all instrument positions, using one or two beams, which have been found satisfactory in practice. This is followed by a chapter on the various terrain, cartographic, and planetary correction methods, and a plotting of the corrected results. Forms and coefficients to facilitate the computation and application of corrections are included. The manipulation of the Askania balances is described in detail with special emphasis on methods of changing wires and adjustments. A valuable up-to-date resumé of efficient methods of torsion-balance field work now employed by oil companies, and short chapters on interpretation of results, application of the method, cost of torsion-balance work, and a selected bibliography complete the book.

Most of the information contained in this handbook is not new to experienced oil-company geophysicists. Some of the forms given have been supplanted by time-saving nomographs or charts. Nevertheless, this little book is a very valuable compendium of the torsion-balance method. It is recommended as a handy reference book for all geophysicists, as a textbook for instruction in the method, and should be in the hands of every torsion-balance party chief.

G. H. Westby

Bartlesville, Oklahoma
February 20, 1933

RECENT PUBLICATIONS

GENERAL

A Manual of Foraminifera, by J. J. Galloway, James Furman Kemp Mem. Ser. Pub. 1 (Columbia University). The Principia Press, Inc., Bloomington, Indiana (1933). 483 pp., 42 pls. of fossils, and frontispiece of D'Orbigny. Cloth. 7×10 inches.

"Contributions of Petroleum Geology to Pure Geology in the Southern

Mid-Continent Area," by Frederic H. Lahee. *Bull. Geol. Soc. Amer.*, Vol. 43, No. 1 (December, 1932), pp. 953–64; 11 figs.; 1 table.

MEXICO

"An occurrence of Upper Cretaceous Sediments in Northern Sonora Mexico," by N. L. Taliaferro. *Jour. Geol.*, Vol. 41, No. 1 (January–February, 1933), pp. 12–37; 7 figs.; 1 table.

NEW MEXICO

"Clastic Plugs and Dikes of the Cimarron Valley Area of Union County, New Mexico," by Ben H. Parker. *Jour. Geol.*, Vol. 41, No. 1 (January–February, 1933), pp. 38–51; 6 figs.; 1 table.

OKLAHOMA

"New Pennsylvanian Conodonts from Oklahoma," by R. W. Harris and R. V. Hollingsworth. *Amer. Jour. Sci.*, Vol. 25, No. 147 (New Haven, Conn., March, 1933), pp. 194–204; 1 plate containing 14 figs.

TEXAS

"The Geology of Hemphill County, Texas," by Lyman C. Reed and Oscar M. Longnecker, Jr. *Univ. of Texas Bull. 3231* (Austin, 1932). 98 pp., 9 figs., 1 map.

"Ground Water Resources of Webb County, Texas," by John T. Lonsdale and James R. Day. *U. S. Geol. Survey Rept. of Investigation* in coöperation with the *Texas State Board of Water Engineers* and the *Eng. Exper. Sta., A. and M. College of Texas.* Mimeographed summary in 9 pp. and 1 map issued as *U. S. Geol. Survey Press Memo.* (February 9, 1933).

"Ground Water Resources of Duval County, Texas," by A. N. Sayre. *U. S. Geol. Survey Rept. of Investigation* in coöperation with the *Texas State Board of Water Engineers.* Mimeographed summary in 14 pp. and 1 map issued, as *U. S. Geol. Survey Press Memo.* (February 12, 1933).

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VOL 17, NO. 4 (APRIL, 1933), PP. 447-449

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

George Dickinson, Birmingham, England
E. Braendlin, D. Trumpy, A. H. Noble
Thomas J. Etherington, Barranquilla, Colombia, S. A.
J. O. Nomland, S. H. Gester, G. C. Gester
Downs McCloskey, Bakersfield, Calif.
C. M. Wagner, Leo S. Fox, E. H. McCollough

FOR ASSOCIATE MEMBERSHIP

Eugene Leonard Earl, Waxahachie, Tex.
W. A. Reiter, Joseph M. Wilson, David J. Crawford
John Joseph Rupnik, Denver, Colo.
F. M. Van Tuyl, Dart Wantland, J. Harlan Johnson

INTERNATIONAL GEOLOGICAL CONGRESS

The third circular for the sixteenth session of the International Geological Congress, which is to meet in Washington, D. C., from July 22 to 29, has been issued. It contains full information about meetings and about excursions, with costs. Before the Congress there are excursions to various parts of the eastern United States, lasting from 4 to 12 days, and a transcontinental excursion eastward from San Francisco for those coming to the Congress from the west. For those arriving at New York too late to take part in these longer excursions there will be a number of short trips to near-by areas of geologic interest.

Alternate days during the sessions of the Congress will be given to excursions to areas around Washington.

After the sessions there will be two longer transcontinental excursions, each lasting 31 days, and two shorter excursions, one for the study of the glacial geology of the central states, the other for the study of the pre-Cambrian area, including the iron and copper deposits, of the Lake Superior region.

In order to make these excursions generally available, it has been possible, through the generous assistance of The Geological Society of America, to offer the longer excursions at a considerable reduction below actual cost.

For special discussion at the scientific sessions in Washington the following topics are announced.

Measurement of geologic time by any method
Batholiths and related intrusives
Zonal relations of metalliferous deposits
Major divisions of the Paleozoic era
Geomorphogenic processes in arid regions and their resulting forms and products
Fossil man and contemporary faunas
Orogenesis
Geology of petroleum
Copper resources of the world

Membership in the Congress is open to anyone interested.

For a copy of the third circular or other information address W. C. Mendenhall, general secretary, U. S. Geological Survey, Washington, D. C.

Applications for membership, accompanied by the membership fee of \$5.00, will be received until the closing date of the session. This fee entitles members to a complete set of guide books for the excursions, even though such members may not be able to attend the functions of the Congress.

For participation in excursions, application should be made before May 1 if possible. For excursions before and during the Washington session, July 1 is assigned as the latest date for application, and for trips after the session, July 15 is the latest date for application.

For geologists of this country who may not be able to go to Washington, but who may wish to join the excursions in the Mid-Continent or West, special rates will be made, but such persons must apply for partial participation and pay the regular membership fee of \$5.00. One of the trips, known as Excursion A6, is scheduled to leave Washington July 11, going via St. Louis to Tulsa, Fort Worth, Houston, and New Orleans, and thence to Washington. For those who would like to join this excursion from Tulsa to Houston, including the Cushing and Oklahoma City fields, Arbuckle Mountains, Ardmore basin and Criner Hills, Van pool, East Texas pool, Palestine and Keechi salt domes, Sugarland salt dome, and Boling salt dome, the cost will be \$35.00, over and above the \$5.00 membership fee.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 4 (APRIL, 1933), PP. 450-452

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

F. A. MELTON, University of Oklahoma, at Norman, presented a paper before the Tulsa Geological Society, March 6, entitled, "Are They Meteor Scars?"

The New Mexico Geological Society, Roswell, New Mexico, sponsored a field trip, February 4 and 5, under the leadership of H. E. QUINN, L. A. NELSON, and BERTE R. HAIGH, of the faculty of the Texas School of Mines. Seventeen geologists from Texas and New Mexico visited the Ordovician section on the east side and fossil localities on the west side of the Franklin Mountains, and the Cambrian-Permian section on the west side of the Hueco Mountains. New officers of the society for 1933 are: president, EDGAR KRAUS, Atlantic Production Company, Carlsbad; vice-president, DELMAR R. GUINN, Empire Gas and Fuel Company, Roswell; treasurer, RALPH KOENIG, The Texas Company, Carlsbad; and secretary, MILWARD MILLER, Humble Oil and Refining Company, Roswell.

C. L. MOODY, of the Ohio Oil Company, Shreveport, Louisiana, talked on the subject of "Cretaceous Problems of the Mississippi Embayment Area," on Thursday, March 9, before the East Texas Geological Society at Tyler, Texas. At the February meeting of the society, G. W. PIRTLE, of the firm of Hudnall and Pirtle, gave a talk on "The Geology of the Michigan Basin Area."

LEWIS W. MACNAUGHTON, geologist with the Amerada Petroleum Corporation, has been transferred from San Antonio to Houston, Texas.

JOHN D. MARR, formerly of Weldona, Colorado, is now with the Independent Exploration Company, with headquarters in the Esperson Building, Houston, Texas.

JAMES R. DAY has resumed work for the Amerada Petroleum Corporation after an absence of two years. He may be addressed at Box 832, San Angelo, Texas.

A. L. ACKERS, geologist for the Stanolind Oil and Gas Company, is now located at Midland, Texas. The company recently moved their offices to Midland from San Angelo. The address is Box 758.

F. M. VAN TUYL, professor and head of the department of geology, Colorado School of Mines, and BEN H. PARKER, consulting geologist, Golden, Colorado, are authors of a paper published in the March 9 issue of the *Oil and Gas Journal* entitled, "Careful Study of Geology of Eastern Colorado Indicates Many Oil and Gas Possibilities." This paper was presented before the joint annual conventions of the Colorado Mining Association, and the Colorado Chapter, American Mining Congress, at Denver.

ERNEST A. OBERING has been appointed district geologist for Shell Petroleum Corporation at San Angelo, Texas, to succeed RUSSELL C. CONK-

LING, who was recently promoted and transferred to Houston. Obering was formerly stationed at Carlsbad, New Mexico.

The Shawnee Geological Society has elected the following officers for the year 1933: president, J. T. RICHARDS, Gypsy Oil Company, Box 967, Seminole, Oklahoma; vice-president, H. M. RUSSELL, Sinclair Prairie Oil Company, Shawnee, Oklahoma; secretary-treasurer, H. C. ARNOLD, Barnsdall Oil Company, Box 97, Earlsboro, Oklahoma.

F. A. A. VAN GOGH, formerly chief of the central geological department of the Bataafsche Petroleum Maatschappij, The Hague, and later geological adviser to that company and the Royal Dutch Shell Combine, has changed his address to Zeekant 108, Scheveningen, The Hague, Holland.

HENRY B. MILNER, consulting geologist and petroleum technologist, London, has recently extended the analytical and testing side of his practice by the completion of a fully equipped new building, "Geochemical Laboratories," at Alperton, Middlesex. His address remains, 92 Victoria Street, Westminster, London, England.

OLIVER B. HOPKINS, chief geologist of Imperial Oil, Ltd., Toronto, Canada, is one of a large party of Standard Oil Company (New Jersey) officials on an inspection tour of South American oil fields.

JOHN G. BARTRAM and HARRY A. AURAND, of the geological department of the Stanolind Oil and Gas Company, have been transferred from Denver, Colorado, to Casper, Wyoming. Bartram was recently elected president of the Rocky Mountain Association of Petroleum Geologists for 1933.

RICHARD E. KOCH, geologist, 30 Carel van Bylandtlaan, The Hague, is making a trip through the California and Mid-Continent oil fields during March, April, and May, after which he will return to Holland.

WARD C. BEAN, geologist for the Shell Petroleum Corporation, Tulsa, sailed March 23 for The Hague, Holland. He will spend about nine months there and in Roumania.

W. W. ORCUTT, vice-president and chief geologist for the Union Oil Company, and honorary member of the Association, has been placed in charge of production and geological operations following the resignation of Paul N. Boggs.

FREDERICK G. CLAPP sailed from New York for Teheran, Persia, March 8, for an absence of several months to advise the Imperial Government of Persia in matters pertaining to oil.

RALPH ARNOLD, geologist and mining engineer, Los Angeles, California, recently went to Oklahoma City, to assist a committee in drafting a new oil and gas bill for proration and conservation.

MARVIN LEE, petroleum geologist and chairman of the Kansas Oil Advisory Committee, Wichita, Kansas, was injured recently in an automobile accident and suffered a slight concussion of the brain.

RAYMOND C. MOORE, University of Kansas, Lawrence, spoke before the Tulsa Geological Society, Monday, March 20, on the subject "The Revision of the Permian and Pennsylvanian Stratigraphy of Kansas."

STANISLAV ZUBER, consulting geologist of the Azienda Italiana Petroli Albania (Italian State Railways), has moved from Lwow, Poland, to Hotel Baston, Rome, Italy, where he is collaborating with the Azienda Generale Italiana Petroli. He has been decorated with the cross of a Commander of the Crown of Italy, conferred by the King for his findings in the Albanian oil fields.

Newly elected officers of the Petroleum Division of the American Institute of Mining and Metallurgical Engineers are: chairman, W. E. WRATHER, consulting geologist, Dallas, Texas; associate chairman, H. NORTON JOHNSON, geologist, Los Angeles, California; secretary-treasurer, E. A. STEPHENSON, professor of petroleum engineering, Rolla, Missouri. Vice-chairmen are: production engineering, H. D. WILDE, JR., Humble Oil and Refining Company, Houston, Texas; production, FRANK A. HERALD, consulting geologist, Fort Worth, Texas; economics, C. B. MAPES, Mid-Continent Oil and Gas Association, Tulsa, Oklahoma; engineering research, K. B. NOWELS, Forest Oil Company, Bradford, Pennsylvania; engineering education, C. M. YOUNG, University of Kansas, Lawrence, Kansas; refinery engineering, WALTER MILLER, Continental Oil Company, Ponca City, Oklahoma; stabilization, EARL OLIVER, Ponca City, Oklahoma.

JAMES O. LEWIS and HARRY F. WRIGHT, consulting engineers, Tulsa, Oklahoma, have an article, "Proration as Based Upon Bottom Hole Pressures and Acreage Most Equitable and Practical," in the *Oil and Gas Journal* for February 23. DUNN and LEWIS and HARRY F. WRIGHT have announced their commercial service in connection with the improved Wright well-pressure gauge with an automatic recording device.

At its meeting on March 9 the Geological Society of Chicago was addressed by Professor NEVIN M. FENNEMAN, of the department of geology of the University of Cincinnati, on the subject "Cyclic and Non-Cyclic Erosion."

The Oil Equipment and Engineering Exposition previously announced at Dallas in April will be held at Houston, Texas, May 22 to 28. G. E. LENZNER, 2519 Gulf Building, Houston, Texas, is general manager.

The West Texas Geological Society will hold its annual field trip on April 29 and 30, to study the Ellenburger limestone section in the Central Mineral Region of Texas. The assembly point will be at San Saba the night of April 28. C. L. DAKE will act as guide, assisted by HENRY MORGAN, PAUL SCHLOSSER, and C. L. MOHR. For additional information and reservations please address Miss MINETTE RIES, Phillips Petroleum Company, San Angelo, Texas.

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